OXYGEN CONSUMPTION DURING EMOTIONAL STIMULATION

STANFORD UNIVERSITY LIBRARY

BY
EDITH TOTTEN

A DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

STANFORD UNIVERSITY LIBRARIES
MEDICAL

1925

781
65T
DECLASSED

OXYGEN CONSUMPTION DURING EMOTIONAL STIMULATION

BY
EDITH TOTTEN

A DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES OF THE JOHNS HOPKINS UNIVERSITY IN CONFORMITY WITH THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

1925

OXYGEN CONSUMPTION DURING EMOTIONAL STIMULATION

EDITH TOTTEN

The Psychological Laboratory of The Johns Hopkins University

CONTENTS

I. Introduction 1
II. Apparatus 3
III. Technique 11
IV. Subjects 14
V. Emotional stimuli 15
VI. Normal records 15
VII. Factors that change the normal angle of the O_2 line 19
VIII. Experiments in emotion 35
IX. Summary and conclusion 76
References 78

I. INTRODUCTION

Ever since James in 1884 and Lange in 1885 suggested the notion that the essential factors of emotion are the bodily changes that occur during the experience, an increasing number of psychologists interested in the study of emotion have directed their attention to a consideration of these changes. In psychological theory the explanation of emotion in terms of organic activity has become well established. Dunlap's statement of the theory (3, p. 318) is as follows:

In the case of anger for instance, a stimulus pattern which may consist of a blow, word or visual details, causes a reaction which terminates in profound visceral disturbances together with somatic changes. The reaction involves the perception of the affront or threat, and its organic termination pattern (involving activities of smooth and striped muscles, glandular activities and probably other chemical changes) really *is* the emotion of anger. This action pattern is also a stimulus pattern, since it stimulates receptors terminating in the visceral and somatic tissues, and thus initiates a new reaction, in

which the emotion is experienced. If the afferent fibers from the soma and viscera were blocked, but the efferent fibers to these tissues not interfered with, the emotion would occur but it would not be experienced.

Equally in experimental investigation of emotion, interest is now directed to the task of determining what, if any, are the bodily changes that occur during the various types of emotional experience, the expectation being that eventually it will be possible to determine experimentally what change or small group of changes is characteristic of and essential to each of the emotions.

While it is easily recognized that changes in tension of the skeletal musculature are commonly a part of the total reaction pattern which occurs with (or *is*) an emotion, yet it seems apparent that the reactions which are essential to emotion are to be sought in the changes in the internal organs. A self-controlled individual may have the keenest subjective experience of fear and yet to outward appearance remain perfectly unmoved, and even to his observation of himself seem to change no muscle. Whether genuine emotion can occur with no changes of tension in the external musculature is a question that cannot now be answered, but these changes may be reduced to a minimum without, apparently, diminishing the intensity or altering the character of the emotion. For this reason, psychological interest tends to centre upon the task of determining what changes occur in internal processes.

Since the consumption of oxygen in the tissues is an indication of cellular activity (7, p. 83), a difference in the rate of oxygen consumption during emotion as compared with the resting state would indicate a change in physiological function; and, if it could be shown to occur when the striped muscles are at rest, it could be taken as an indication of change in internal function. But it would be only a very general indication; it would tell us nothing of what specific organs were affected. Furthermore, the rate of oxygen consumption at a given moment would indicate only the balance struck by the activities of all the organs. For example, a given emotion might be accompanied by increased activity of certain organs and decreased activity of certain others;

and, if these counterbalanced each other, the effect would be no change in the rate of total oxygen consumption for the body, just as if no functional change had occurred at all. Or if the increase were in excess of the decrease, the result would be an increase of oxygen intake for the body although certain activities had been diminished.

However, in spite of the very general nature of the information to be hoped for through a study of oxygen consumption during emotion, it is not without its value. If it should prove to be possible to classify human emotions into two groups, i.e., emotions which involve an increase of body metabolism and emotions which involve a decrease, the classification would be not only of general scientific interest but of considerable practical usefulness.

So far no studies of oxygen consumption during emotion have been published, and the work to be described here was undertaken as a first step in that direction.

II. APPARATUS

The apparatus that was chosen for this study is a modification of the Benedict Portable Respiration Apparatus, which was developed by Dr. Paul Roth (12). It was chosen rather than gas analysis, because it does away with the need of the coöperation of a skilled gas analyst, and at the same time it was hoped that it would give measurements of oxygen consumed during an experimental period that would be entirely adequate for an investigation of this character. The apparatus measures only the oxygen consumed in a given period, without furnishing a means of measuring at the same time the elimination of carbon dioxid. But it was not thought that the latter measurement would be of any interest in itself, in this connection, or that it would be of any aid in interpreting the results of oxygen measurement, owing to the fact that changes in the degree of lung ventilation cause changes in carbon dioxid output by pumping out the gas from the blood during increased ventilation and storing it in the blood during decreased ventilation, although no measurable change in body oxidations may have occurred; and as will

soon be seen by a glance at the records, the most immediate, most usual and most conspicuous effect of emotion is to alter the rate and depth of breathing.

The apparatus has also what seemed a great advantage in that it makes possible a continuous graphic record of the amount of oxygen consumed before, during, and after the time in which the emotional experience occurs. It will be seen later what the limitations of the method proved to be, and also in what respects it proved valuable.

A brief description of the Benedict apparatus with the Roth Modifications will be sufficient here. A diagram of the instrument is given in the accompanying cut (fig. 1). It consists of a spirometer, *A*, to be filled with oxygen, in the center of which is set a can, *B*, containing soda lime as an absorbent for carbon dioxid. Two tubes, *C* and *D*, connect one, *C*, with the bottom of the spirometer and one, *D*, with the bottom of the soda lime bottle, both being attached at the other end to the metal mouthpiece assembly, *E*. Through *C* oxygen is inhaled from the spirometer chamber, and through *D* the expired gas is sent back into the soda lime bottle, *B*. A rubber valve, *F*, in the tube, *C*, prevents the expired gas from passing through *C* into the spirometer chamber. After passing through *D* and the soda lime can where its carbon dioxid is taken from it, the expired oxygen enters the spirometer chamber through the valve, *G*. This valve prevents oxygen from being drawn down through the soda lime can into the lungs.

With the movements of the spirometer bell in inspiration and expiration, a counter-weight, *H*, with a small pointer attached, slides up and down in a slot, the pointer moving along a millimeter scale, *I*, placed at the side of the slot. Fixed to the counter-weight is a binding post to which is attached a longer pointer which moves up and down against the surface of a revolving kymograph drum. When the longer pointer and kymograph are used, the short pointer and millimeter scale serve only in regulating the amount of oxygen let into the spirometer.

As the movements of the counter-weight are in the opposite direction to those of the spirometer bell, they are in the same

direction as the movements of the chest in breathing, and inspiration is recorded on the smoked paper of the kymograph as an upward stroke and expiration as a downward stroke. The length of the upward stroke measures accurately the height of the volume of oxygen taken out of the spirometer at a breath, and since the bell has a volume of 20.73 cc. per millimeter of its

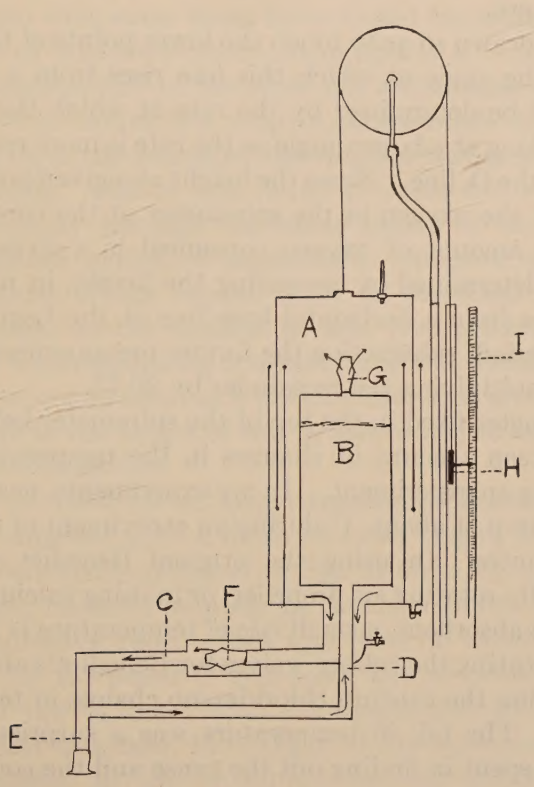

FIG. 1

height, the number of cubic centimeters inhaled at each inspiration can be determined by multiplying the length of the upward stroke by 20.73. The length of the downward stroke, made by the rise of the bell as the oxygen deprived of its CO_2 returns to the spirometer in expiration, measures the amount of oxygen exhaled in the same way. But since a certain amount of oxygen

is consumed in the tissues at each inspiration, the volume of oxygen returned to the spirometer at each expiration is less than the volume taken from it in the preceding inspiration. Thus the downward stroke is in general shorter than the preceding upward stroke, and the record on the smoked drum crosses the paper diagonally, as may be seen by reference to the records reproduced here.

If a line is drawn so as to touch the lower points of the respiration curve, the angle at which this line rises from a horizontal base line will be determined by the rate at which the oxygen is consumed, rising at a larger angle as the rate is more rapid. This line is called the O_2 line. Since the height at a given point records the height of the oxygen in the spirometer at the corresponding moment, the amount of oxygen consumed in a given period of time can be determined by measuring the height, in millimeters, of the O_2 line from a horizontal base line at the beginning and end of the period, subtracting the former measurement from the latter, and multiplying the remainder by 20.73.

A thermometer fixed in the top of the spirometer bell makes it possible to keep account of changes in the temperature of the oxygen during an experiment. In my experiments, nearly always there was a drop of about 1° during an experiment of thirteen or fourteen minutes. In using the original Benedict apparatus, with its rapidly rotating air propeller, or in using calcium chloride as a moisture absorbent, a small *rise* of temperature is looked for. But in substituting the rubber valves for Benedict's air propeller, and in omitting the calcium chloride, no change in temperature is expected. The fall in temperature was a surprise. Several periods were spent in finding out the cause and the course of this change. It was apparently due to the fact that the air of the room in which the apparatus was set up, cooled off very much during the night and the water seal, in which the spirometer bell is suspended, with it. In the morning the room air became quickly warm, but the water seal less quickly—there might be a difference of 1° or 1.5° at the beginning of an experiment on the days when this matter was tested out. The spirometer bell was always filled with oxygen at least half an hour before the experi-

ment began, and during the following hour or half hour the temperature of the oxygen in the lifted bell would tend to approach that of the room air, though remaining at the beginning of the experiment a little below it. As soon as the subject began to breathe from the spirometer, the bell would descend, of course, more and more deeply through the water seal. This continuous plunging into cool water must have cooled the walls of the bell, which must in turn have cooled the oxygen in it. On warm days when the temperature of the room did not change much during the twenty-four hours, the drop in temperature did not occur. On several days the course of the drop in temperature was followed carefully, and it was found to occur not suddenly but always gradually through the whole course of the thirteen or fourteen-minute period of experiment. Since a change of 1° in temperature of the oxygen must be corrected by only 0.5 mm. of oxygen in the apparatus, this very gradual fall of 1°, or 1.5° and a corresponding contraction of the volume of oxygen, could not be looked upon as a possible source of error in estimating a change in the height of the O_2 line at a specified point, i.e., following a stimulation.

In order to allow for as long a tracing as possible, the kymograph was supplied with a drum of extra height, 27 mm. The paper was fastened together about the drum in the ordinary way, but was then fastened securely to the drum in two places at the top with adhesive tape. This was done in order to make it impossible for the paper to slip down and so cause a change in the level of the O_2 line. With the height and circumference of the drum that was used, the oxygen of the spirometer was just about exhausted in one revolution, leaving enough oxygen in the spirometer to make the routine test for CO_2 at the end of each experiment. About six litres of oxygen was let into the spirometer for each experiment.

Since the question of interest was a change in the rate of oxygen consumption as an indication of increased or decreased function of the internal organs, it was necessary, if possible, to have some means of knowing whether or not any changes in tension of the external musculature occurred. To this end a series of acces-

sory apparatus was devised consisting first of tubes of thin rubber (for which ordinary drainage tubing was used) which were provided with muslin casings so that one could be bound around the calf of each leg, one about each fore-arm, and one about the body, crossing the upper abdomen. Each of these tubes was sealed at one end while the other end was cemented about a rubber stopper with a hole through it. In this hole was inserted a short piece of glass tube which fitted tightly in the hole. A rubber tube connected the outer end of the glass tube with a similar glass tube inserted in the rubber stopper of an aspirator bottle. Over the end of the glass tube which projected beyond the stopper inside

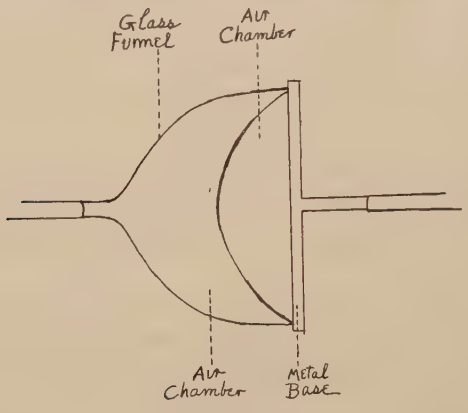

Fig. 2

the bottle was fastened the mouth of a small balloon of very thin rubber. For the later experiments two of these bottles were done away with and two "capsules" designed by Dr. Dunlap were substituted for them (fig. 2). The capsule consisted of a funnel-shaped glass cup fastened tightly around its edge to a flat metal base from the centre of which opened a short metal tube. Before clamping the glass cup and metal base together, a piece of rubber dam was stretched across the latter. A rubber tube connected the metal tube of the base with the rubber tube around the subject's leg, while another rubber tube connected the stem of the funnel-shaped cup with a tambour. When the closed system formed by the rubber dam, the metal base of the

capsule, the rubber tube about the leg, and the tubing connecting them, was inflated, the dam bulged into the glass cup, and any change of pressure in the tube about the leg caused a change of pressure upon the air in the glass cup and so in that of the tambour.

Each of the aspirator bottles, already described, was also connected with a tambour by rubber tubing from its outlet. Two T-tubes were inserted in the rubber tubing which connected each drainage tube with its balloon or capsule, and a short length of rubber tube was drawn over the free end of each T-tube, so that by clamping this rubber tube a closed circuit could be obtained. By means of one T-tube outlet, the system of tubes and balloon or capsule could be temporarily connected with a mercury manometer; and by means of the other the drainage tube, bound around the arm, leg or body, together with the balloon or capsule connected with it, could be inflated, the pressure being determined and kept constant from experiment to experiment by reference to the manometer. After the pressure had been regulated, the T-tube outlet was closed and connection broken with the manometer.

By this system of inflated tubes, movements of the arms, legs or body could be recorded on the kymograph drum. The device was delicate enough to record the pulse from the legs and sometimes also from the arms. Movements of a toe or finger could be detected. Slow muscular tensions were also recorded, as was shown by having the subjects voluntarily tense their muscles. As experiments progressed, however, and the work on emotion developed, the usefulness of the pneumatic tubes proved to be limited for two reasons. In the first place they gave no measure of the amount of movement or of tension recorded. The construction of apparatus for such a purpose is in itself matter for research and is still a thing of the future. In the second place, by the nature of their structure, these tubes must act as crude plethysmographs and must register any pronounced volumetric changes in the limbs. Hence in tracings taken during periods of emotional excitement, when vascular changes are almost certain to have altered the volume of the limbs and consequently the

pressure on the tubes, and when the subject's report indicates that muscular tensions have occurred, there is no way of distinguishing with any satisfactory degree of certainty between the effects of the two disturbances. As will be seen, a measured record of slow sustained tension proved to be a thing much needed in the interpretation of results.

Respiratory movements of the chest were recorded by a pneumograph fastened about the chest, but the importance of having this record was not appreciated at first and consequently some of the records lack it.

Movements of the abdominal muscles in respiration were recorded by means of the rubber tube about the body.

A pulse record was obtained by means of a shallow cup, shaped like a small flattened funnel, with a rubber membrane stretched over its mouth, and a rubber tube connecting its stem with a tambour. The membrane of the cup was placed over the left carotid artery and held in place by an ordinary clamp such as is used by bicyclists to hold the trousers tight around the ankle. A hole through one end of the clamp held the stem of the cup. By bending the clamp the membrane could be pressed closely over the artery and be held firmly about the neck. Since the clamp is a broken circle, it can be placed about the back and sides of the neck and at the same time leave the trachea free from contact with it. An attempt was made to record the apex beat but this proved very unsatisfactory. The carotid pulse gave much more satisfactory results, though not completely so, since its record is interrupted by swallowing movements. Usually, however, these movements were not frequent enough to destroy the usefulness of the record. Unfortunately, in reproducing the records for publication it has been necessary to reduce them to such an extent that the individual pulse beats cannot be counted. The waves that are to be seen in the reproduced tracings are, of course, respiration waves; the pulse waves have been run together. Reports of changes in the pulse count, made on the basis of the original records, are given in the text in connection with each experiment.

A time recorder, operated by an electric clock and marking

every five seconds was used in all but a few early experiments where a Petzold clock was used, marking every ten seconds.

A stimulus recorder completed the assemblage of apparatus.

III. TECHNIQUE

The purpose of the experiments was to compare the rate of oxygen consumption during a period of emotional disturbance with the rate during the period immediately preceding (the fore-period) and that immediately following the disturbance. Obviously, in order that such a comparison should have any meaning, the factors influencing metabolism during the whole experiment period must be controlled. Otherwise any change during emotion could not fairly be attributed to its influence. The series of movement recorders is, of course, one means of controlling the situation to this end. It was also necessary to eliminate the influence upon metabolism of digestion and assimilation and thus reduce the consumption of oxygen to the minimum necessary for the mere upkeep of the bodily processes. The subjects, therefore, came to the laboratory in the morning at 9:00 or 9:30, at least twelve hours after eating. Just before the experiment, they had at least half an hour of complete rest in the wheeled chair in the position in which they were to remain during the experiment. As a matter of fact, they had much more than half an hour of rest, since the adjustment of the tubes, pneumograph, and pulse recorder took nearly half an hour, during which the subjects lay covered with a blanket, with only occasional movements, though usually with some conversation. The half hour's complete rest without conversation followed the adjustment of the tubes, etc. During the complete rest the subject lay on his back in the chair, which was adjusted so that a comfortable reclining position was assured. The head was supported by a pillow, the back by a folded blanket, and the arms and legs were so supported at the elbows, hands, knees, and feet that the rubber tubes did not come in contact with the arms or with the leg-rest of the chair. The subject was thoroughly comfortable and relaxed, lying usually with closed eyes during

the rest period, and was required to make no further movement except such slight ones of head and mouth as were necessary in order to receive the rubber mouthpiece in the mouth.

During the experiment a folded piece of gauze was laid over the subject's eyes so that they would be kept closed and the attention of the subject would not be so readily attracted to the objects in the room and the movements of the experimenter.

During the half hour rest period the pointers of the seven tambours and of the time and stimulus records were adjusted to the drum, and at the last minute, before adjusting the mouthpiece, the temperature of the oxygen in the spirometer was taken.

The procedures recommended for the care of the apparatus, for testing for leakage, for testing for carbon dioxid in the oxygen at the end of an experiment, and for the usual method of adjusting the mouthpiece and nose clip are to be found in Dr. Roth's papers referred to above (12). It was found, however, that reliance could not be placed upon the nose-clip to prevent breathing through the nose, unless it was carefully tried out at the beginning of each experiment, before adjusting the mouth-piece. At the end of the rest period, therefore, the nose-clip was placed on the subject's nose and screwed to what seemed a reasonable degree of tightness. The subject was then asked to close the mouth and blow *hard* through the nose. If any air escaped, the clip was tightened or perhaps placed in a different position. This meant that the nose-clip was tighter than would be at all comfortable if it were worn only once, but every one of the subjects was practised during at least eight periods, distributed over several days, and soon became accustomed to the pressure of the nose-clip as well as to the other conditions of breathing from the apparatus. As soon as the nose-clip was in a satisfactory position, the mouth-piece was adjusted. In order to spare the subject all muscular movement and also because by this time the rubber tubes around the arms were inflated, the mouth-piece was placed in the subject's mouth by the experimenter, wearing rubber gloves for the purpose and helping the subject to get the lugs between the teeth and the lips about the phlange. The lips

were then drawn about the stem of the mouthpiece. During this operation, the subject's tendency is to hold the breath, which causes very irregular breathing for some time after the beginning of the experiment. A warning against this, and practise, do away with this tendency. Nevertheless, I usually allowed the subject to take a few breaths before starting the kymograph.

The desirability of remaining motionless and relaxed during the experiments under all circumstances was impressed upon all subjects. As a result of the amount of practise that the subjects were given, they were able, unless disturbed, to maintain the required position with relaxed muscles and to breathe comfortably and with fair regularity through the tubes of the apparatus. Thus it was possible to get, in the fore-period of an experiment, a record from which the rate of oxygen consumption under basal conditions could be determined, and the rate during and after emotional excitement could be compared with it.

As the point of interest in the experiments was this comparison, and the determination of the basal metabolic rate of the subjects was not in itself of interest, no attempt has been made to make this determination with the corrections for temperature and barometric pressure that would be necessary. With each record, however, is given the temperature of the oxygen immediately before and immediately after the experiment, so that the amount of the variation that has been described as due to the influence of the water-seal may be clear in each case.

Since the total time during which an experiment could be run was limited to thirteen or fourteen minutes, the time for each part of the experiment was brief. At first I tried to divide the total experiment period somewhat evenly into three parts; but, as experiments progressed, the importance of a longer record following the period of emotional disturbance became clear and the fore-period was therefore shortened. The rigid limitation of the time that could be given to an experiment was one of the disadvantages which attached to the use of this apparatus. This difficulty might be remedied by the construction of a respiration apparatus of greater capacity and the use of a correspondingly

larger drum. One difficulty, however, in greatly prolonging the experimental period would arise from the fact that the longer the time during which a given position is to be maintained, the greater is the tendency for fatigue, restlessness and tension to set in. However, a period of more than fourteen minutes could probably be used, and the subject could be made comfortable through practise.

In determining the point at which the stimulus was to be introduced, I had to keep in mind: (*a*) The necessity for getting a long enough record of regular breathing to give the rate of oxygen consumption under basal conditions; and (*b*) the need for an adequate record of the recovery from emotion. And of course this point varied with the subject's behavior in each experiment. It was always necessary to delay the stimulus until after the record of the spirometer tracing had risen above that of the abdominal respiratory movements, in order that the changes in each should not be obscured by the crossing of one over the other.

IV. SUBJECTS

The subjects who served for these experiments were as follows:

T. A., male, aged twenty, a student in the Senior class.

M. B., female, aged thirty, a graduate student in Philosophy.

M. K., female, aged twenty-one, a graduate student in Philosophy.

V. D., female, aged forty-eight, a graduate student in Psychology.

D. W., male, aged twenty-two, a graduate student in Political Science.

No records of emotion were obtained from D. W.

Three other subjects served for short periods and for preliminary experimentation.

All of the subjects were to a certain extent "selected." They were asked to act as subjects because they were known to be persons of some degree of sensitiveness. The difficulties of rousing emotion under laboratory conditions are so great that no experiments are likely to succeed unless a selection of this sort is made.

V. EMOTIONAL STIMULI

The stimuli used were in no case of the simple sensory sort designed to give rise to the so-called affective states of "pleasantness" or "unpleasantness." It was my wish to rouse the more complicated states to which we usually apply the name "emotion"—such states as are described as fear, or apprehension, or pity, etc. Not all the stimuli were applied to each subject. At the end of an experiment the subject was questioned as to how the stimulus had affected him, and an emotional state was held to have been secured only when his report warranted it.

VI. NORMAL RECORDS

Three records (figs. 3, 4, and 5) are given as examples of undisturbed periods for D. W., M. B., and M. K.

By way of illustrating the method, the rate of oxygen consumption has been worked out for these subjects.

In these, as in all other records, corresponding points in the different tracings are indicated by the same letter.

All records have been reduced to two-fifths of their original size.

In figures 3, 4 and 5 the white line drawn tangent to the lower points of the respiration curve is the so-called "O_2 line." The amount of oxygen consumed during any portion of the period is found, as has already been said, by measuring the height of this line above a horizontal base line, as the stimulus line, at the beginning and at the end of the part of the period in question, and by then subtracting the first from the second. The difference between the two, expressed in millimeters, is then multiplied by 20.73 which gives the number of cubic centimeters of oxygen consumed.

Since the breathing is never absolutely regular, the respiration curve does not touch the O_2 line at the end of every downward stroke; hence the O_2 line must define the approximate average of the distances above the stimulus line, by being drawn so as to allow the occasional deeper expirations to drop below it and the occasional shallower ones to clear it.

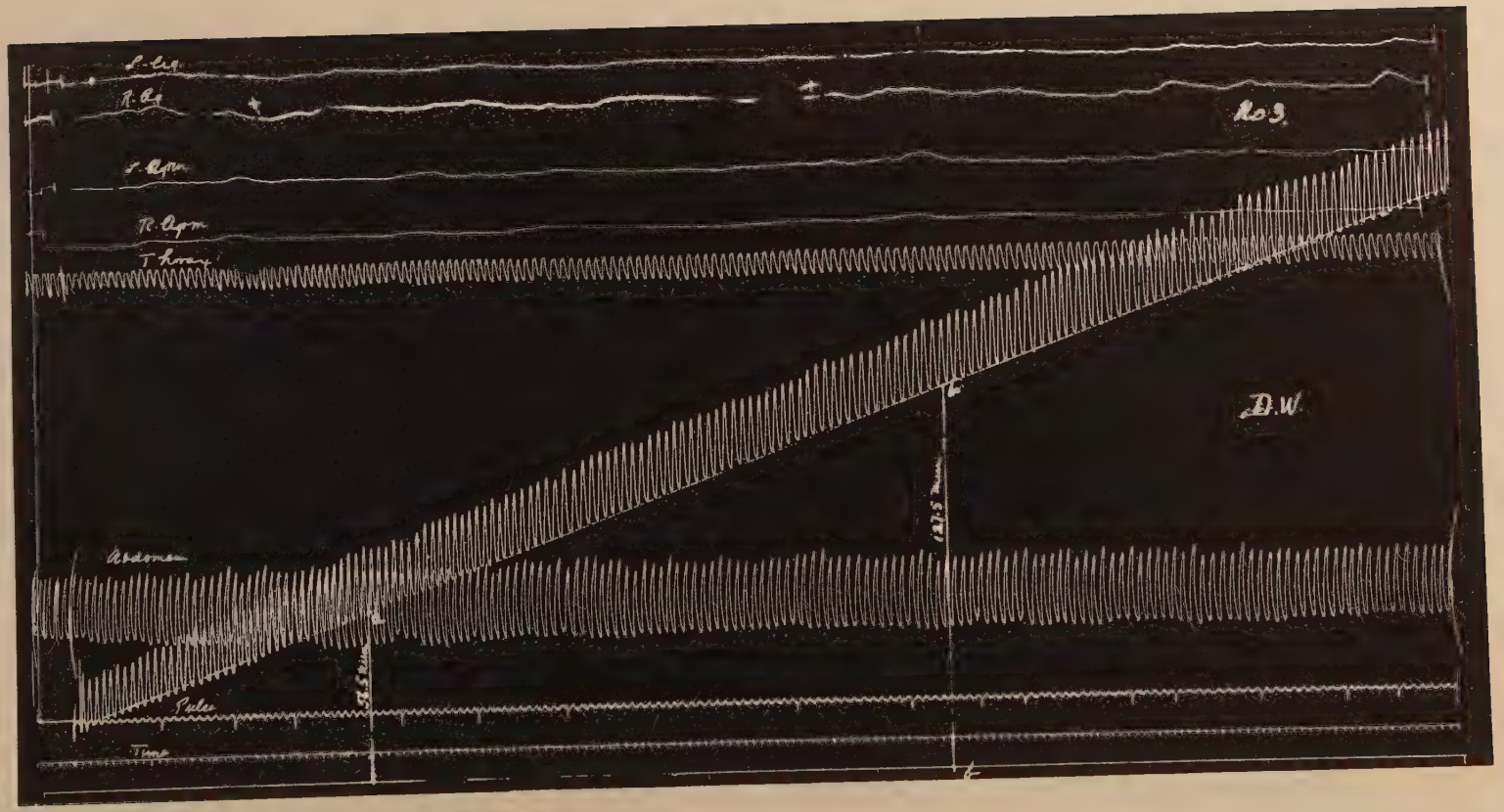

FIG. 3

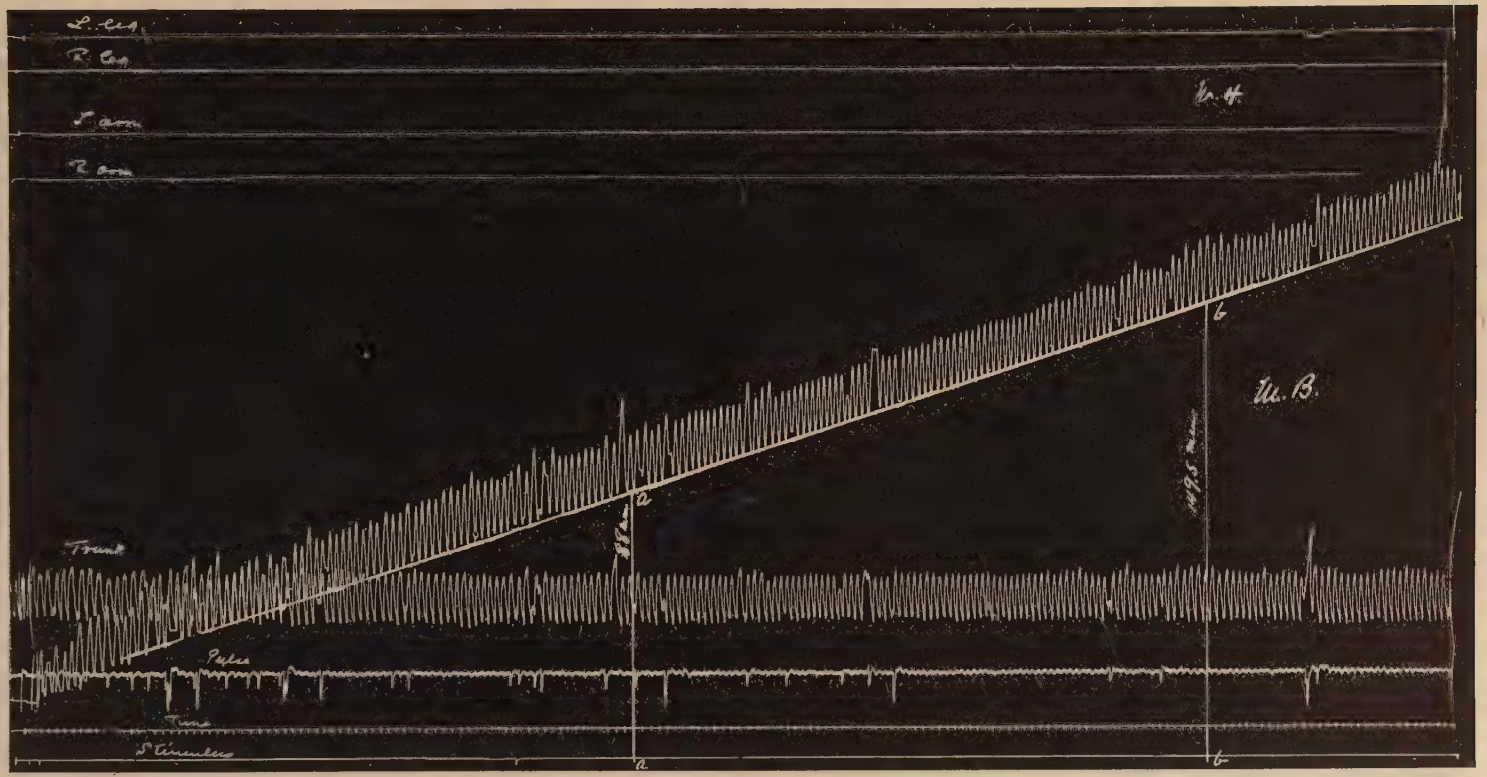

FIG. 4

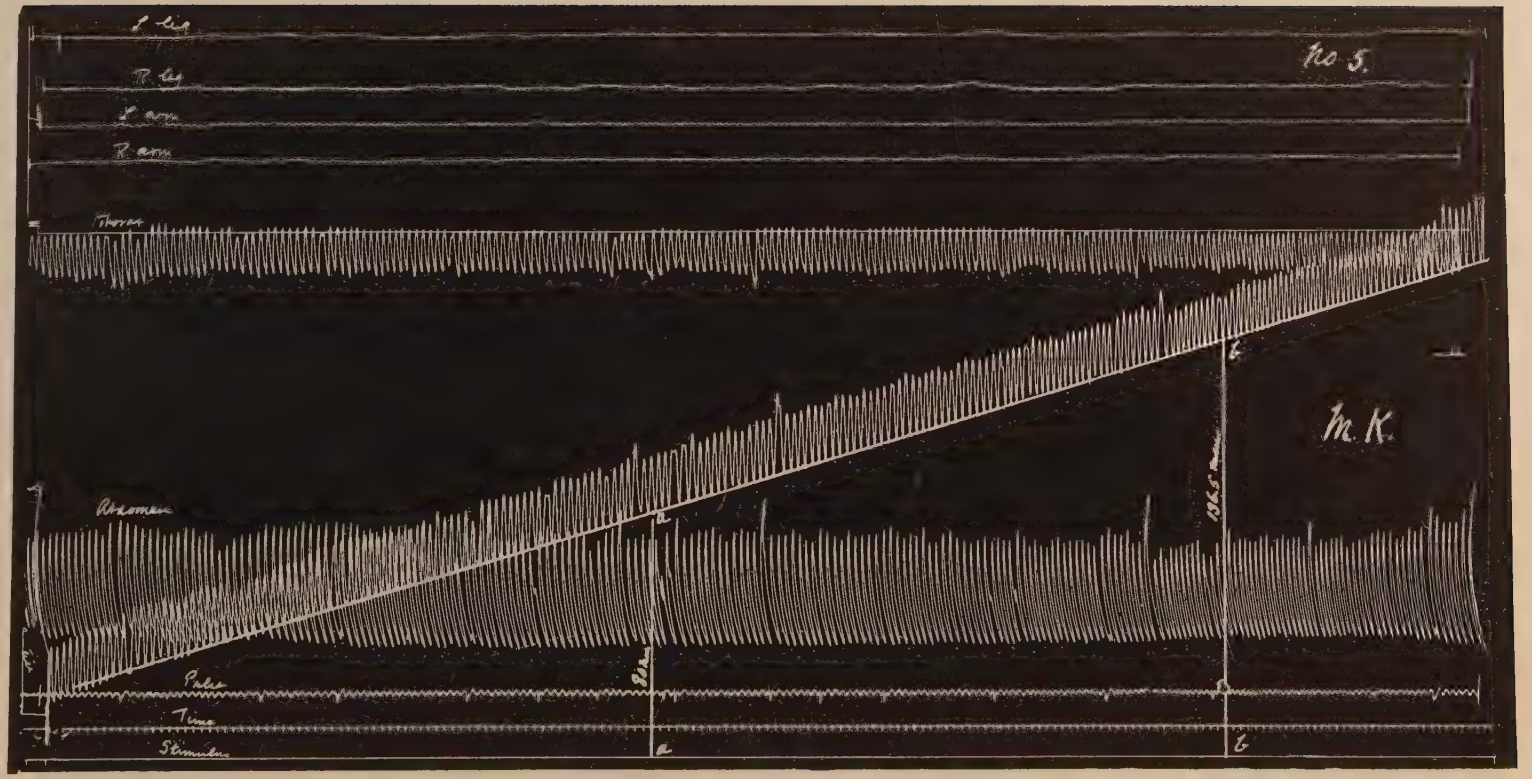
L leg
R leg
L arm
R arm
Thorax
Abdomen
Pulse
Time
Stimulus
No 5.
M. K.
a
b

FIG. 5

The points marked *a* and *b* on the stimulus line have been selected to delimit a period of six minutes for which the rate of oxygen consumption is to be calculated.

In figure 3, the perpendiculars *aa* and *bb* measure respectively 56.5 mm. and 127.5 mm. The difference is 71 mm., and this multiplied by 20.73 gives 1471.83 cc. oxygen consumed in six minutes; the rate of consumption being, then, 245.3 cc. per minute for D. W. By similar calculations, figures 4 and 5 show that M. B. and M. K. were consuming oxygen at the rates respectively of 212 and 195 cc. per minute.

VII. FACTORS THAT CHANGE THE NORMAL ANGLE OF THE O_2 LINE

When it comes to interpreting the changes in the O_2 line during periods disturbed by emotional stimulation, the task is by no means simple. More than one factor may cause a change in the slope of the line, and before turning to the records of experiments in emotion it is necessary to discuss the known factors of this sort.

1. The O_2 line may be made to change its level by changes in the completeness with which the lungs are emptied at expiration. If expiration suddenly becomes less complete, more oxygen will be withheld in the lungs at each breath, and the O_2 line will proceed at a higher level than before. Similarly a change to deeper expiration will cause the O_2 line to fall below its previous level. In either case, if no change in oxygen consumption has occurred, the O_2 line will resume its original level and angle when normal breathing is resumed. In these cases, when tracings of thoracic and abdominal respiration are taken, the lift or drop of the O_2 line will be accompanied by a simultaneous change in the level of these tracings, or of one of them, showing an increased or decreased expansion of the chest or abdomen, or both.

2. Another cause for a lift in the O_2 line proved to be an increase in the depth of breathing; that is, an increase in the volume of oxygen taken into the lungs at each breath. In the earliest records of emotion that I obtained, an increase in depth of breathing during the period of emotional stimulation and a

simultaneous rise of the O_2 line were very conspicuous features. (Figures 15 and 17 will illustrate this.) In order to elucidate the connection between this respiratory change and the rise in the O_2 line, and in order to determine whether or not the latter occurred only during deep breathing in emotion, a number of experiments were tried in which at a signal the subject voluntarily increased the depth of breathing, resuming normal breathing at a second signal. Figures 6 (T. A.), 7 (T. A.), 8 (D. W.), and 9 (D. W.), show the results.

It is seen in all of these records that the lower border of the respiratory tracing rises above the original O_2 line simultaneously with the increase in depth of breathing; and that when respiration begins to return to normal, the tracing slowly approaches the original O_2 line meets it at *d* and continues with it for the rest of the experiment.

The depth and rate of breathing were both varied, and it was found that the lift of the O_2 line was greater as the depth of inspiration was greater and also when the rate increased with the depth. These variations may be seen in figures 6, 7, 8 and 9. If the subject was instructed to breathe more deeply, but slowly enough to feel that each expiration had been complete, the rise of the O_2 line was slight, as in figure 10 (T. A.). If respiration was very slow and the expirations very much forced, so that an extra amount of oxygen was forced from the lungs, the effect of deep breathing on the O_2 line could be avoided, as in figure 11.

Obviously, then, the O_2 line rises above its normal path during deep breathing whether emotion is present or not.

The question of the mechanism by which the O_2 line rises in response to deep breathing then demanded consideration. In figures 6, 7, 8 and 9, the rise of the O_2 line is clearly not due to incomplete expiration, since the thoracic and abdominal tracings both show that the expiratory movements during the forced breathing were greater than or equal to those of the fore-period, that is, they are greater during the period *b-c* than before *b* or after *c*. (It is the upper border of the curve that is to be observed in the thoracic tracings and the lower border in the abdominal

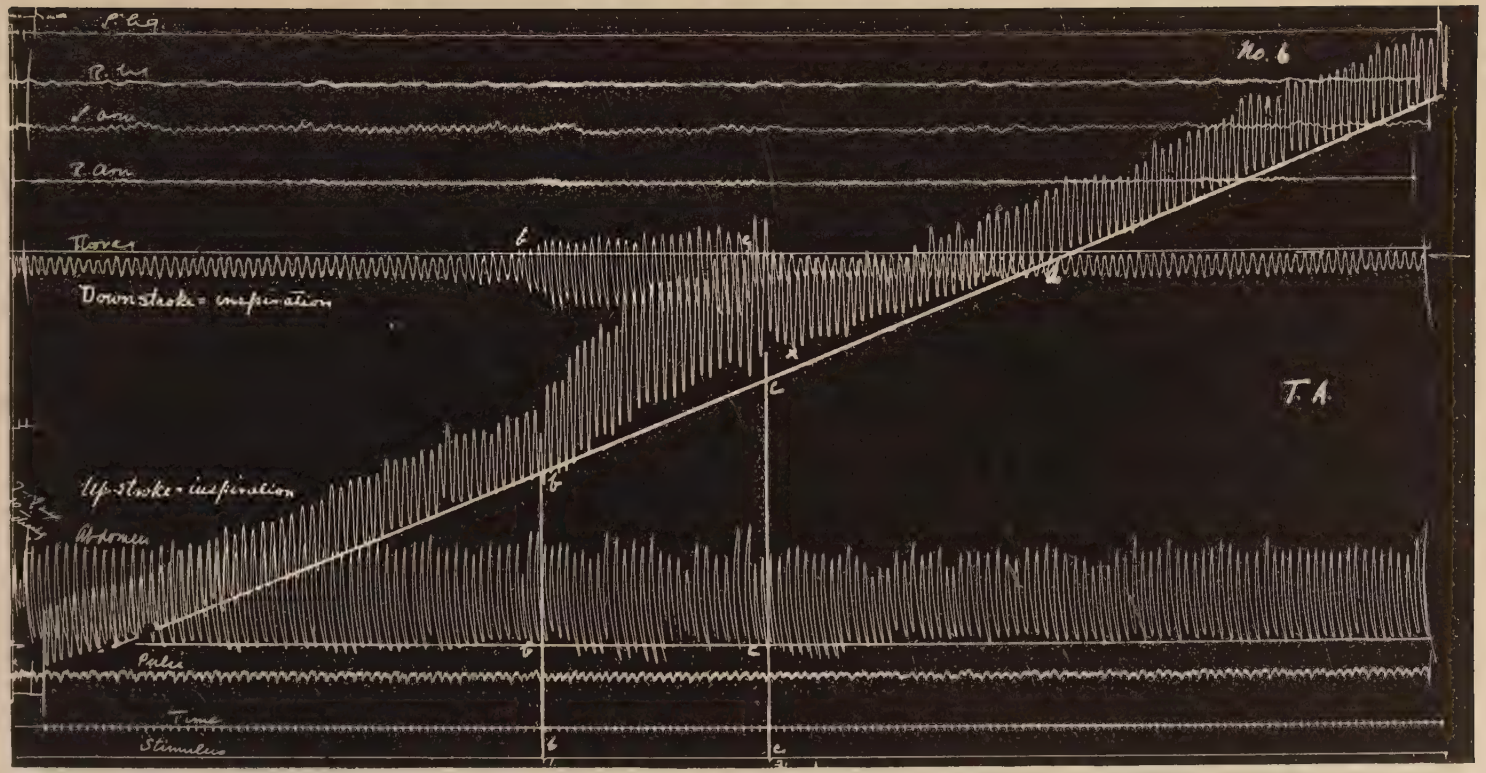
No. 6
T. A.
Down stroke = inspiration
Up-stroke = inspiration
Abdomen
Pulse
Time
Stimulus

FIG. 6

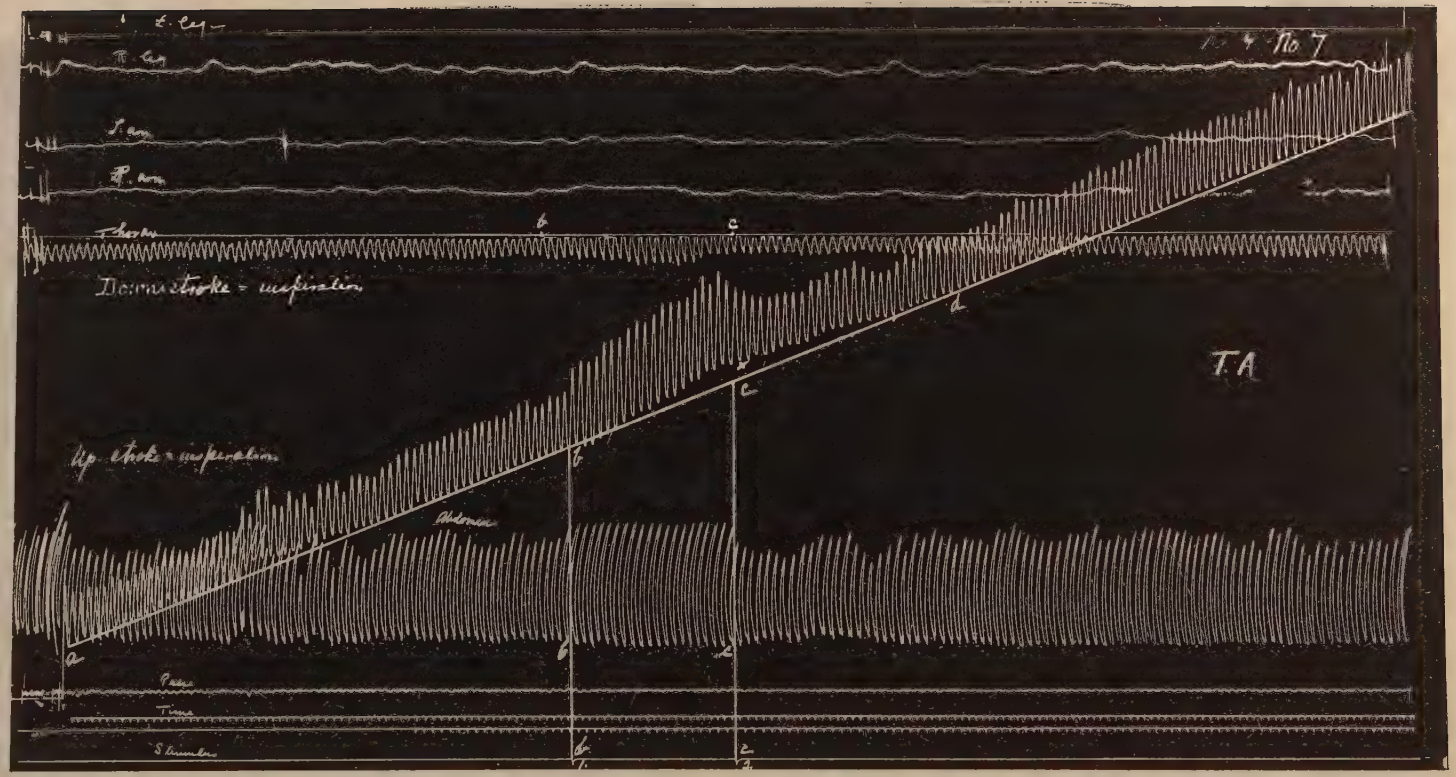
No 7
Thorax
Diam. stroke = inspiration
T.A
Up. stroke = inspiration
Abdomen
Press
Time
Stimulus

FIG. 7

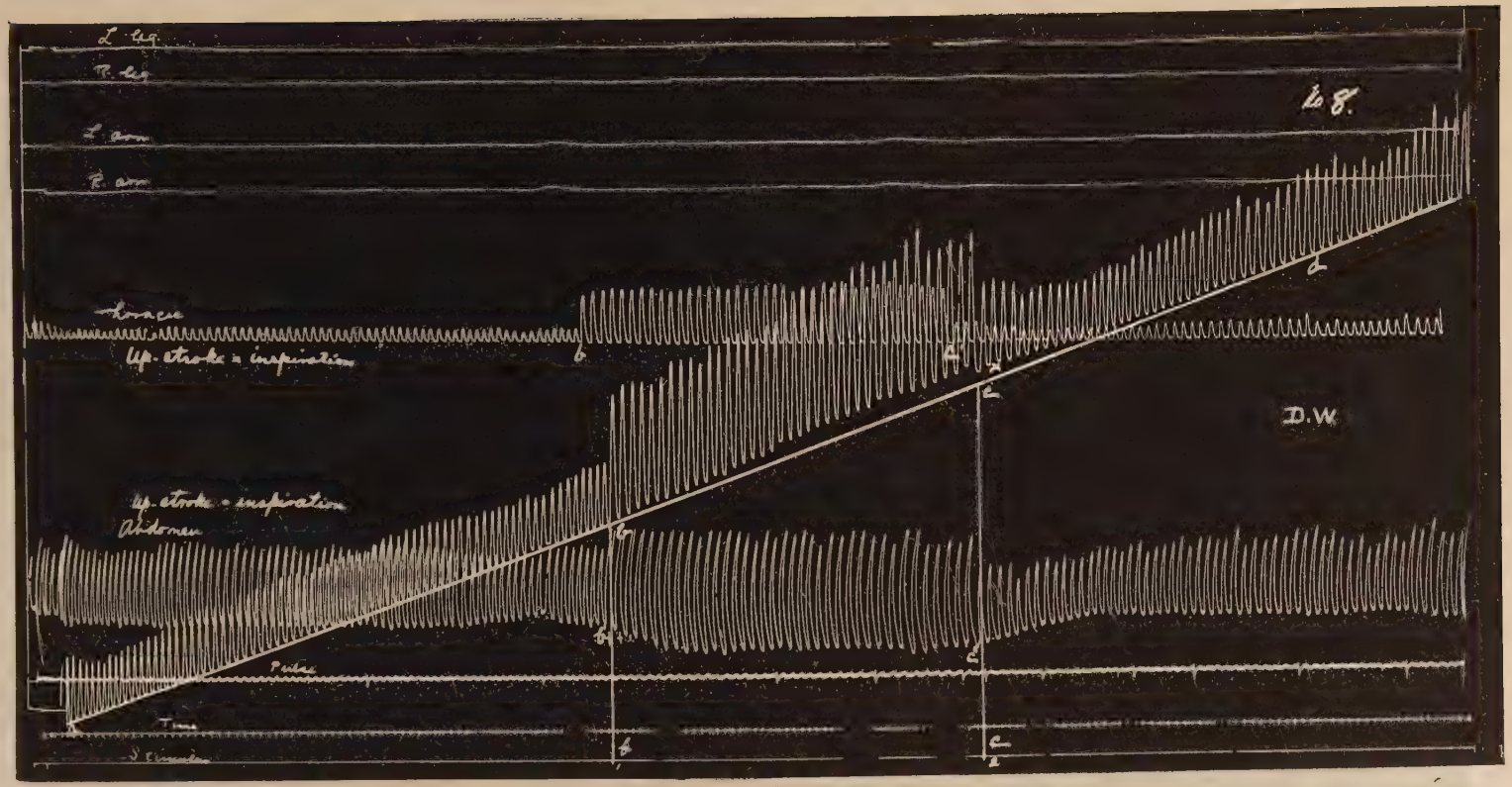
L leg
R. leg
L arm
R. arm
Trachea
Up-stroke = inspiration
Up-stroke = inspiration
Abdomen
Pulse
Time
1 Second
No 8.
D.W
a
b
c
d

FIG. 8

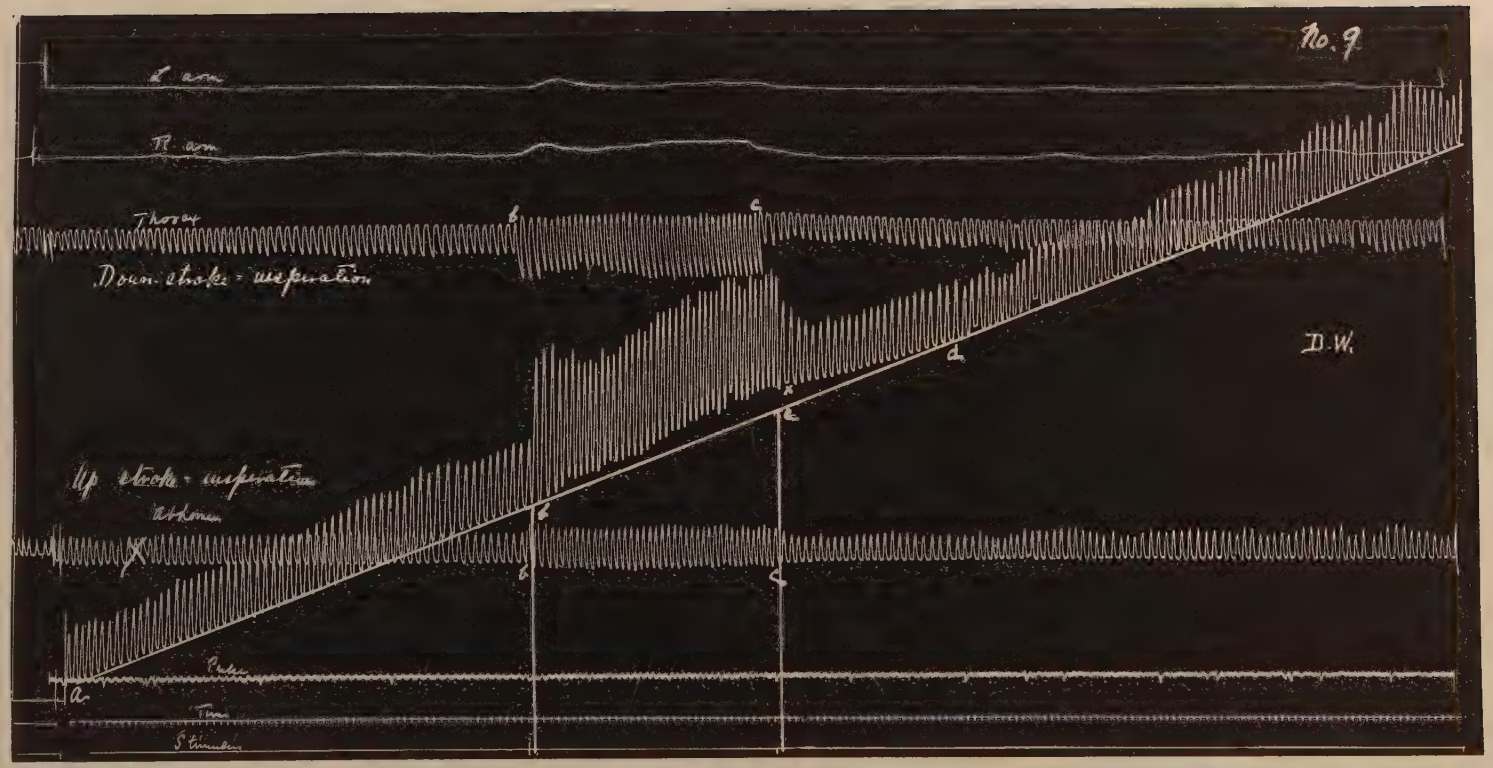
No. 9
L arm
R arm
Thorax
Down stroke = inspiration
D.W.
Up stroke = inspiration
Abdomen
Pulse
Time
Stimulus

FIG. 9

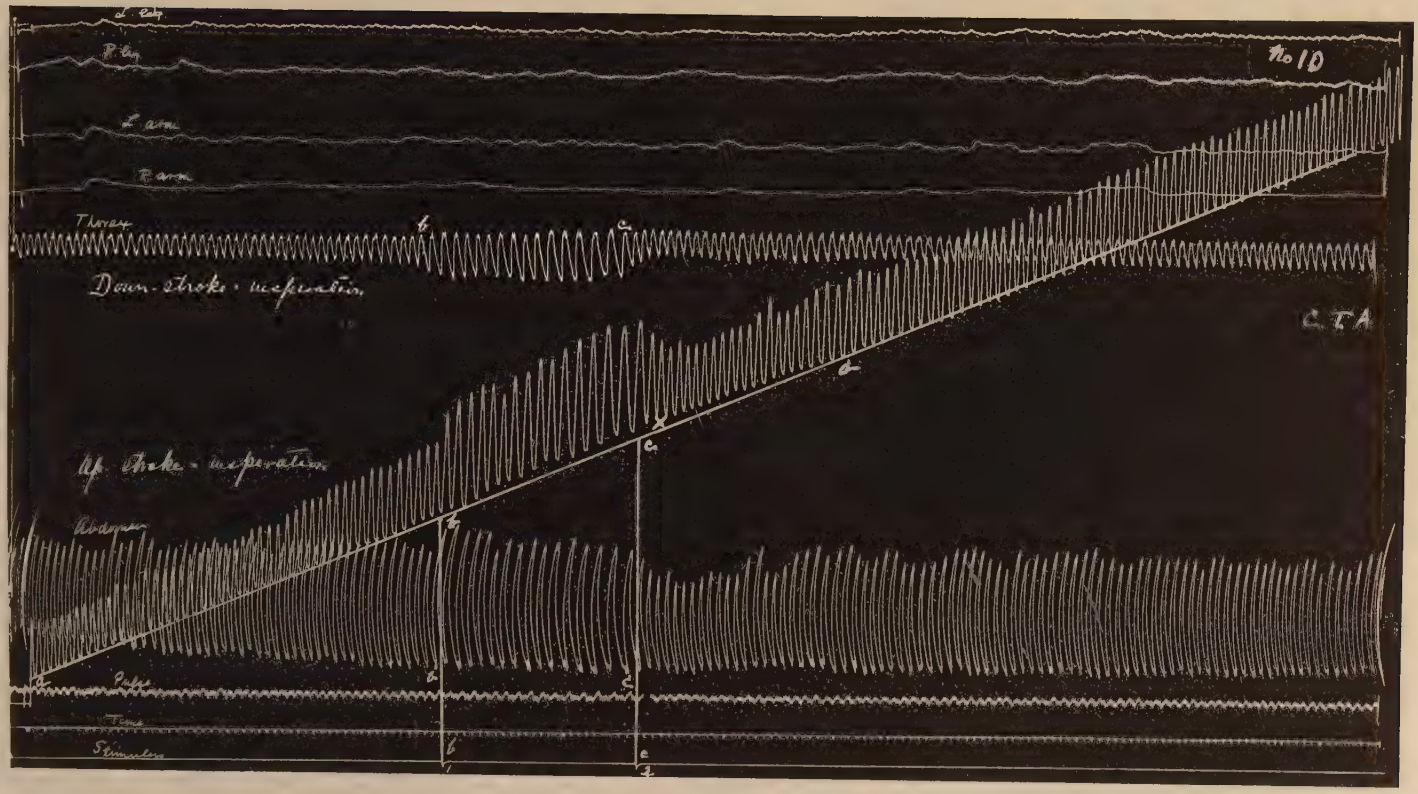
No 10
Thorax
Down-stroke - inspiration
C. T. A.
Up-stroke - inspiration
Abdomen
Pulse
Time
Seconds

FIG. 10

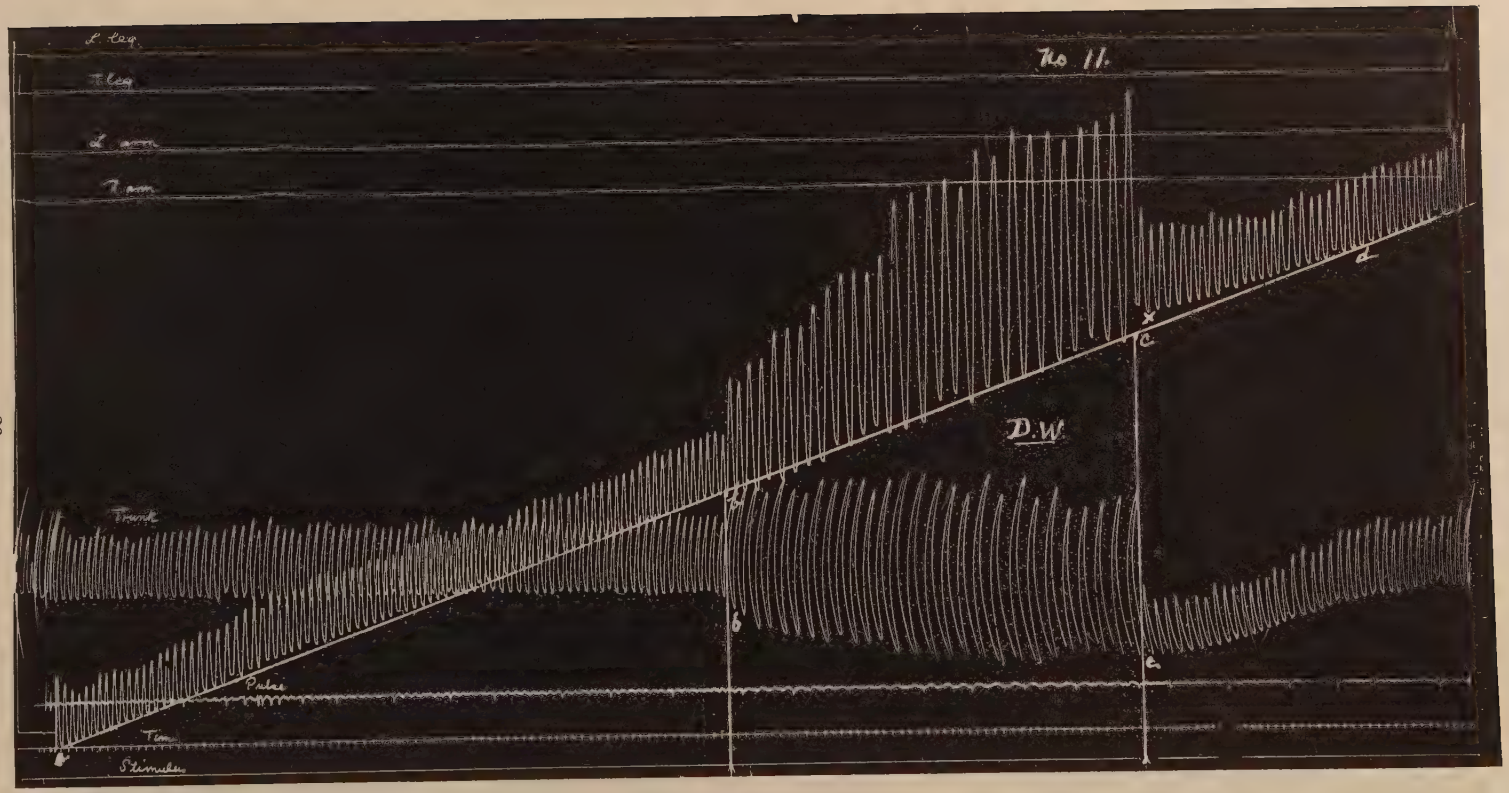

FIG. 11

tracings, except in figure 8, where the lower border indicates the extent of the expiratory movements in both tracings.) In other words, the expansion of the chest and abdomen is less at the end of each expiration during hyperpnea than during normal breathing, or else it is the same in both. The expansion of the lungs at the end of each expiration can, therefore, not be greater during deep breathing, and the lift of the O_2 line cannot be attributed to the retention of oxygen in the lungs.

The question must then be considered whether the rise of the O_2 line can be the result of a genuine increase in oxygen consumption due to increased activity of the respiratory muscles. In examining the tracings we have seen that although the O_2 line rises during hyperpnea, it returns again very gradually at the end of the hyperpnea to the same level it would have had had there been no interruption, and then continues for the rest of the experiment at its original slope and level. The records of D. W. show this most clearly because of the great regularity of his breathing. If an increase in the rate of oxygen consumption is the cause of the rise of the O_2 line from *b* to *x*, then the period *x-d*, in which the O_2 line proceeds at a less slope than in the fore-period, must be explained as due to a decreased rate of consumption, as compared with the fore-period, immediately following the hyperactivity of the respiratory muscles and balancing the previous increase. This increase of rate followed by a decrease should also be found in all cases of muscular activity. But from the work of Verzar and that of Hill (1, pp. 77–80) on the call for oxygen in single muscles, it is clear that the increased rate of oxygen intake due to muscular activity continues for some time after the muscle has ceased to contract, and that there is no period of a rate slower than normal occurring before the return to normal. Also Krogh and Lindhard (8), in work-experiments with the bicycle ergometer, found that the rate of oxygen consumption remained above the resting level for varying periods of time after the cessation of work, although the gradual decline of the rate from the maximum began almost at once after the cessation of work.

Some explanation, other than a continued expansion of the

lungs or increased oxygen consumption resulting from activity of the expiratory muscles, must then be sought for the rise of the O_2 line in deep breathing. Obviously a portion of the oxygen inhaled is withheld temporarily in some way not inconsistent with a reduction in the girth of chest and abdomen and a corresponding deflation of the lungs. The explanation is to be found, I think, in the fact, demonstrated by Krogh and Lindhard (9), Haldane (4), and others (5, 6, 11), that during deep breathing the capacity of the dead space is increased either by mechanical stretching of the walls of the bronchi and bronchioles, or through the activity of the broncho-dilator nerves whose presence has been demonstrated in the bronchial muscles (2). The investigators who have studied this matter seem to be agreed on the main point, that deep breathing causes an increase in the dead space, but whether this increase comes about through stretching or through nervous activity does not appear to be agreed upon. The question of how great the increase may be is still a matter of disagreement. Haldane as well as Henderson and his co-workers (6) maintain that the capacity of the air passages may be as great as 600 or 700 cc. in deep breathing, while Krogh and Lindhard (8) and Pearce and Hoover (11) believe that the increase above the normal cannot be more than 100 or 115 cc.

It might appear that even though the walls of the bronchi and bronchioles do become expanded during an unusually deep inspiration, they should return to their normal state at each expiration and so have no effect upon the level of the O_2 line. The fact that the O_2 line rises and maintains a higher position during a considerable period must be explained as due to the rapidity with which one inspiration follows another without allowing time for the bronchi and bronchioles to be emptied sufficiently to return to their normal capacity. The facts already referred to—(*a*) that if the subject breathes deeply but very slowly, as in figure 10, the O_2 line does very nearly keep to its original level; and (*b*) that the height of the O_2 line above its original level is greater when increased rate is added to increased depth of respiration—point to this explanation. At the end of hyperpnea, on the other hand, when respiration again becomes

slower and shallower during the period *c-d*, the bronchial muscles return to their normal tension, and the stored up oxygen is slowly expelled, partially compensating for the oxygen that is consumed in this period, and therefore causing the O_2 line from *c* to *d* to proceed at an angle less than normal.

That a considerable increase in the capacity of the dead space could occur and persist for a period of time without causing an expansion of the chest seems possible. As Pearce and Hoover point out (11), the area of a circle varies as the square of its radius, and a slight increase, therefore, in the diameter of the bronchi and bronchioles would cause a relatively large increase in the cross section of these passages. It is easily possible that room could be made in a contracted thorax for the greater circumference of the passages by the compression of the softer tissues surrounding them.

3. Finally, the O_2 line may be made to rise by an increase in rate of oxygen consumption. If there were no interruption to the regularity of breathing during the period of increased rate, the O_2 line should simply change its angle, rising with a steeper slope. When, however, the period of increased rate is marked by great irregularity of respiration, the O_2 line may be so broken that it proceeds at no determinable angle, or the effect of deepened breathing added to that of increased consumption may disguise the angle. In these cases, however, if the period of increased oxygen consumption is followed by a return to regular breathing, the O_2 line of the after-period will lie above the level of a continuation of the original O_2 line. If, in this after-period, the original rate of oxygen consumption has been reëstablished, the O_2 line of the after-period will run parallel to that of the fore-period but at a higher level. Examples of this may be seen in figures 12 (T. A.), 13 (M. B.) and 14 (M. K.), in which the subjects were subjected to a series of severe electric shocks which caused a very large amount of muscular activity, even more indeed than the tracings indicate. At each shock the subject's head and shoulders and legs were drawn up convulsively from the chair.

In each record the last shock occurred at *c*, but the O_2 line in figures 13 and 14 continues to rise at a steeper slope than normal

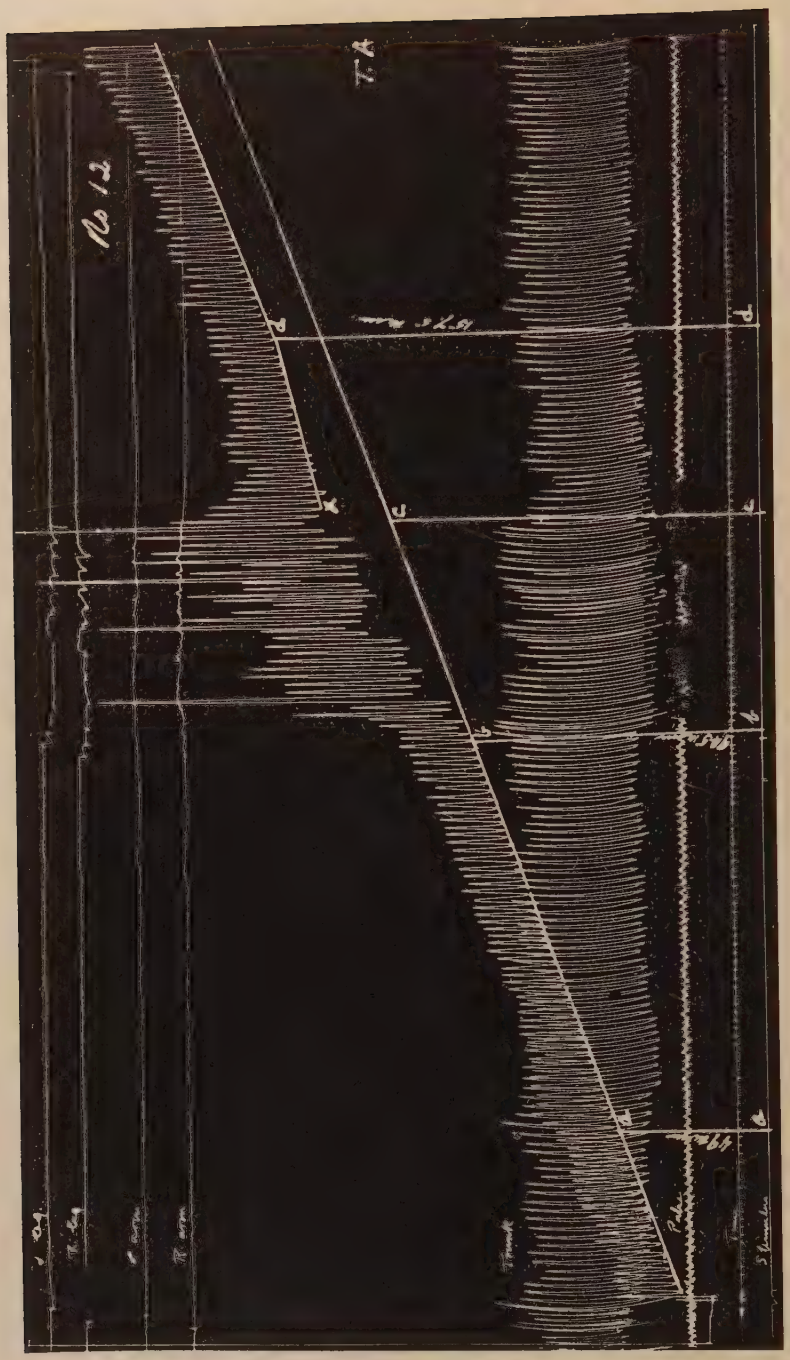

Fig. 12

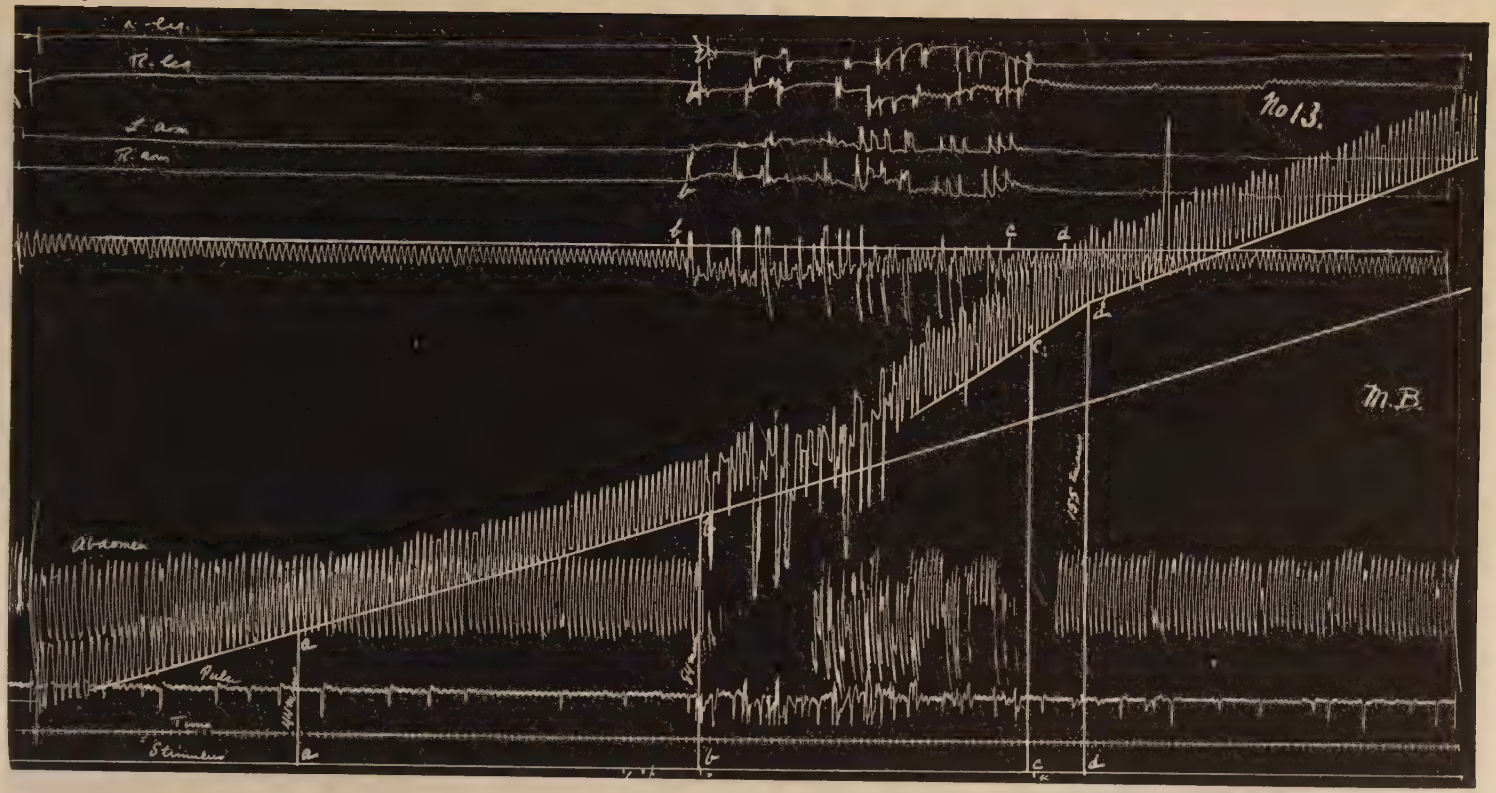

FIG. 13

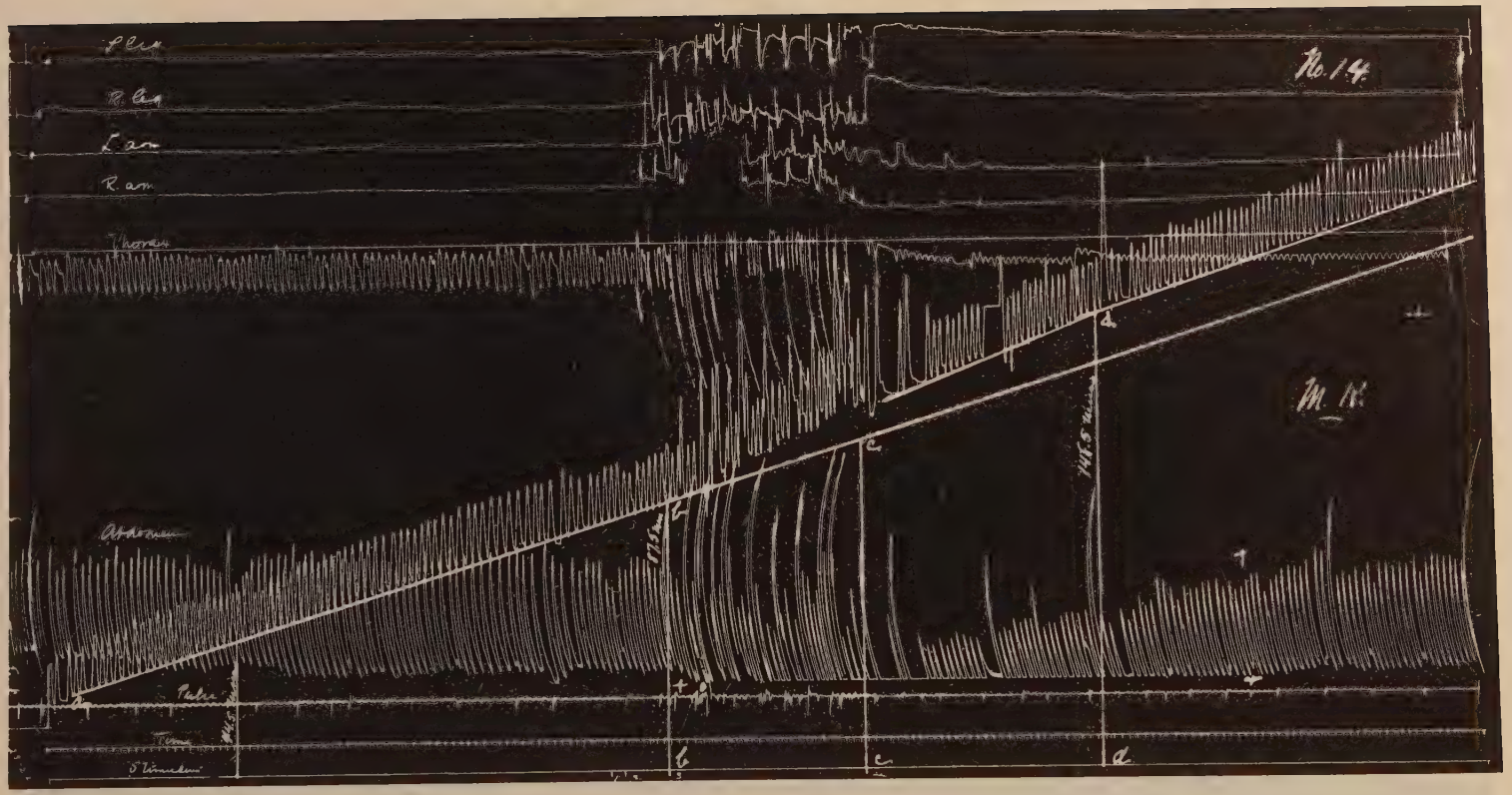

Fig. 14

up to *d*. In figure 14 it resumes practically the normal angle beyond *d*, but continues at a much higher level. In figure 13 also, the line beyond *d* continues at a higher level than the original line, but it does not resume the normal angle during the experiment, indicating a very slightly higher rate of oxygen consumption after *d* than before *b*. These two records are surprisingly free from the effect of hyperpnea, and the influence of increased oxygen consumption on the O_2 line is well seen, especially the continuance of the increased rate after the cessation of activity in striped muscle. In figure 12, however, there is very pronounced hyperpnea from *b* to *x* with an exaggerated height of the O_2 line due to it. Thus we have here the typical effect of the recovery from hyperpnea, from *x* to *d*, disguising the real rate of oxygen consumption in this short period. Beyond *d*, again, the O_2 line proceeds at a somewhat steeper slope than the original line and at a much higher level.

This continuance of the O_2 line at a higher level than it would have maintained had there been no interruption to it, as seen in all three of these records, is the essential indication of an increase in the rate of oxygen consumption during a period of disturbance, provided that the higher level is not the result of continued deep breathing or of incomplete expirations. M. B.'s breathing in figure 13 is slightly deeper beyond *d*, than in the normal period, and probably this accounts for a very small part of the height of the line during the after-period. The thoracic and abdominal tracings, however, show that incomplete expirations are not responsible for any part of it. In figures 12 and 14, respiration resumes its normal depth at *d*. And while the thoracic tracing is lacking in 12 and is meaningless in 13, owing to the pneumograph's having been broken by the subject's movements, yet the abdominal tracing indicates deep exhalations.

It must be said, of course, that in these experiments the electric shocks caused not only a large amount of muscular movement but also profound emotional disturbance. Hence the changes that appear in the O_2 line show not only the result of increased oxygen consumption due to activity of striped muscle, but also show whatever effect emotion may have upon the O_2 line. I have

used the records here merely to show the effect on the O_2 line of increased oxygen consumption, because the large amount of movement leaves no doubt that there has been such an increase.

If, in such records as these, the increase in the rate of oxygen consumption is to be measured, it is a question just at what point after the cessation of movement the second measurement should be taken. Certainly it cannot be taken in any of them before *d*. In figures 13 and 14, the increased rate which continues so strikingly from *c* to *d* is as much the result of the disturbance during *b*-*c*, as is the rate of this period itself; and in figure 12 it is not possible to tell at what point between *x* and *d* the quicker rate began to be modified. The slightly faster rate of oxygen consumption that appears in figures 12 and 13 from *d* to the end of the experiment is also a result of the activity of *b*-*c*; but if this total increase is to be calculated, it should be done, I think, with reference to *b*-*d* and the period beyond *d*, separately. I have taken the measures at *a*, *b*, and *d*, calculating only for the period of maximum increase.

Record shown in figure 12:

In period *a*-*b*, 94.32 cc. of oxygen consumed.

In period *b*-*d*, 1305.9 cc. of oxygen consumed.

Each period is 4 minutes.

Therefore the rate for *a*-*b* is 235.8 cc. per minute, and the rate for *b*-*d* is 326.4 cc. per minute, an increase of 38 per cent.

In this experiment there was no change in temperature. The thermometer registered 21.5° both before and after the experiment.

Record shown in figure 13:

In period *a*-*b*, 829.2 cc. oxygen consumed.

In period *b*-*d*, 1471.8 cc. oxygen consumed.

Each period is 4.3 minutes.

Therefore the rate for *a*-*b* is 192.8 cc. per minute, and the rate for *b*-*d* is 342.2 cc. per minute, an increase of 77.4 per cent.

The temperature was not recorded.

Record shown in figure 14:

In period *a*-*b*, 891.3 cc. oxygen consumed.

In period *b*-*d*, 1263.5 cc. oxygen consumed.

Each period is 4.6 minutes.
Therefore the rate for *a-b* is 193.7 cc. per minute, and the rate for *b-d* is 274.8 cc. per minute, an increase of 41.8 per cent.
The temperature dropped from 23° to 22°.

VIII. EXPERIMENTS IN EMOTION

In discussing the experiments in emotion, I shall group them according to the person who acted as subject. The discussion of each experiment will be headed by its number, the initials of the subject, and a statement of the temperature of the spirometer immediately before and immediately after the experiment.

Experiment 15. Subject T. A. Temperature 22°–22°

The stimulus for this experiment was an alarm of fire and the sounds of extinguishing it outside the experimenting room. For a number of days I had been using Victrola music as stimuli, and no other form of emotional stimulation had ever been tried with this subject. On the morning of this experiment, the Victrola was in the room and open, with a record in place, as it had been on the preceding days, so that the subject expected the usual thing. Without his knowing it, the door had been left ajar, and Dr. Dunlap stood just outside to get my signal. A moment after I signalled, at the first mark on the stimulus line (fig. 15), someone was heard running down the hall; a woman's voice in suppressed excitement called out that there was a fire in her room. Dr. Dunlap called to one of the men; there was the sound of more running and of the fire hose being dragged along the hall. Then Dr. Dunlap's voice was heard, "Break that glass," followed by the sound of smashing glass. Immediately before the second mark on the stimulus line, Dr. Dunlap's voice was heard saying "That's all right," and the disturbance subsided.

The subject was completely taken in, as were other persons in the laboratory who had not been warned. His first remark at the end of the experiment was "You got a lot more from that than from any music." His account of his reaction was:

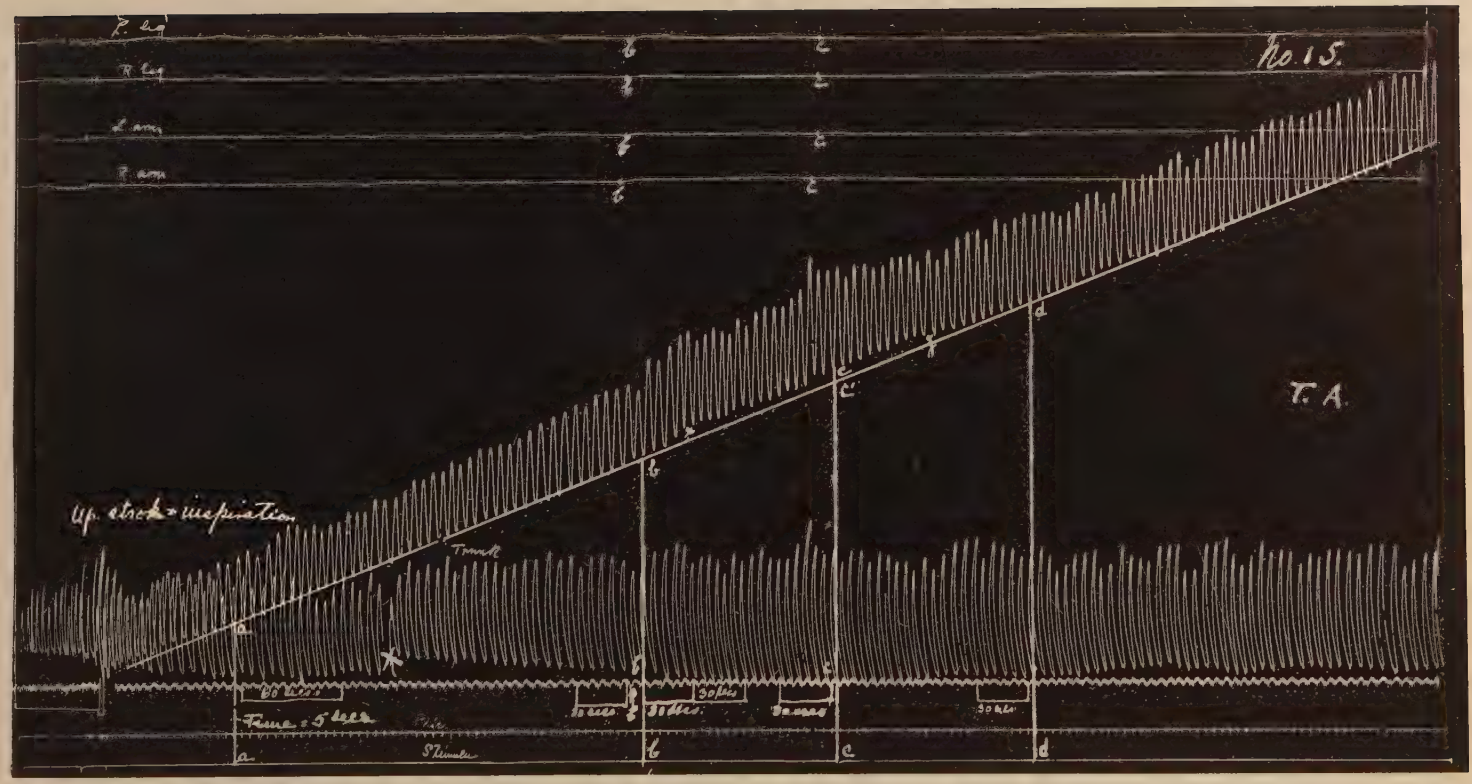

FIG. 15

"Rather great excitement with a large factor of wonder." "I was hungry when I started this, but I got so excited that I've got over it."

The record shows deeper and quicker respiration beginning at *b*, which corresponds with the first stimulus mark. The O_2 line rises rapidly, maintains its higher position up to *c*, then slowly approaches the original line and meets it at *d*, proceeding with it from there to the end of the experiment. We have here, then, evidently, an example merely of the effect of hyperpnea. This effect I have suggested is to be explained as a retention of oxygen in the dilated bronchi and bronchioles, during the deeper breathing, followed for a brief period by a slow return of the retained oxygen to the spirometer as the air passages resume their normal state. There is no indication of an increase in the rate of oxygen consumption.

The tracings from the arms and legs show no muscular disturbance.

The pulse rate increases from 25 beats in the last thirty seconds before the beginning of stimulation to 33 beats in the first thirty seconds after the beginning of stimulation, to 32 beats in the second thirty seconds after the beginning of stimulation, and to 35 beats in the last thirty seconds in the period of stimulation. Stimulation was continued one minute and fifty-three seconds, approximately. The per minute pulse rate, therefore, for the fore-period is 50 beats per minute, and for the stimulation period, 66, 64, and 70 beats per minute. About one minute and fifty seconds after the cessation of stimulation, the pulse had returned to its normal rate of 50 beats per minute.

Experiment 16. Subject T. A. Temperature 21.5°–21.5°

I had found in talking with this subject in connection with an experiment with Victrola music, that he could, with considerable ease, induce an emotional state by absorbing himself in the thought of a certain girl of his acquaintance. For this experiment he was asked to do this when I gave the signal, "Now," which I did at the point *b* on the stimulus line (fig. 16). His account of the experience was substantially as follows: During

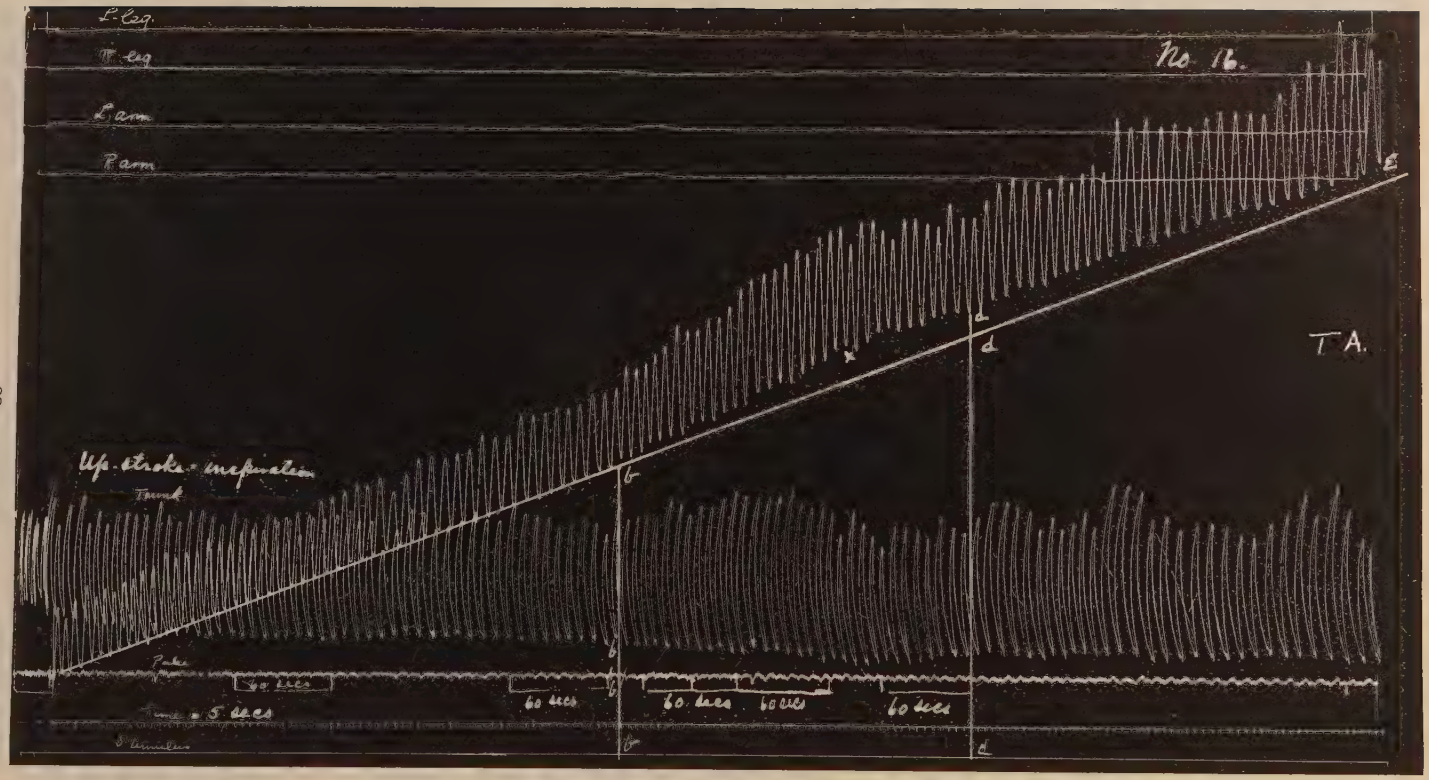
L. Leg.
R. Leg
L. arm
R. arm
No. 16.
T A.
Up-stroke - inspiration
Trunk
Pulse
60 secs
60 secs
60 secs
60 secs
60 secs
Time = 5 secs
5 minutes
a
b
c
d
e
x

Fig. 16

about the first minute after the signal, his thoughts centered upon the girl of whom he had previously spoken, and in this period the emotional state was "generalized sex desire," such as may be satisfied by "going to church" with the person who is its object. Then his thoughts wandered to other girls of the same type. During this period the state was a kind of excitement, or pleasure, and "general systemic feeling" as if the blood had become delightfully cool. This was very real, so much so that he could clearly delimit the period during which it occurred. His thoughts turned then to girls of a quite different type, and the feeling became "specific sex desire," roused by the thought of individuals but not directed towards individuals. He thought, all through, of the girls as being actually present by calling up their images and got whatever emotional excitement would have been roused if he had been in their presence. The whole thing wore off, finally, and he was just beginning another attempt, when I brought the experiment to a close.

The record shows deeper breathing and the characteristic rise of the O_2 line beginning at *b*, and continued to *X*. At this point the lower border of the spirometer tracing, or the upper O_2 line as it may be called for convenience, begins to approach the lower one. It does not however meet it, but turns at *d* and continues parallel for a time and then drops slightly nearer to it towards the close of the experiment.

This continuance of the upper O_2 line parallel to and at a higher level than the lower one, appears at first sight to indicate an increased rate of oxygen consumption during *b-d*. This, however, cannot fairly be claimed in view of the very definite way in which respiration continues abnormally deep straight through to the end of the experiment. If no other factor were present and the deep breathing had been continued voluntarily from *d* to *e*, we should expect exactly the effect the record shows. It is possible, of course, that an increase of oxygen consumption has occurred and that its effect is masked by that of deep breathing; but if so, there is no way here of distinguishing between the two.

The arm and leg tracings show no indications of muscular movement.

In each of the two 60 second periods marked off on the pulse tracing in the fore-period, there are 54 beats; in the 60 seconds marked off just after the beginning of stimulation, there are 63 beats; in the second period of 60 seconds after the beginning of stimulation, there are 60; and in the third, there are the normal 54 beats.

Experiment 17. Subject T. A. Temperature 19°–19°

Three days before this experiment, T. A. had been subjected to a series of electric shocks, the effect of which has been shown in figure 12. Experiment 12 had been carried through expressly for the purpose of establishing an attitude favorable for the present one. A buzzer had been connected with the apparatus with which the electric shocks were given, and had been so arranged that it could be sounded both when the current was being sent through the electrodes and when it was not. In experiment 12 the buzzer was sounded continuously during the time when the shocks were being given and also for 30 seconds before the first shock. In this way the subject was trained to expect a series of shocks to follow the sounding of the buzzer.

In no. 17 the buzzer was sounded alone, beginning at *b* and stopping at *c* (fig. 17). The subject really expected the shock. He was not afraid of it; but the shock experiment had been very painful, and he described the present experience as "disagreeable anticipation" and "excitement." He found it impossible to describe the experience any more clearly, "perhaps because I have never felt that way before." "I don't know just how to describe that, but I don't like it, I can tell you that." But he thought the excitement was not as great as in experiment No. 15 during the "fire." He also said that, when the buzzer stopped at *c*, he had no sense of relief, thinking that I meant to give him a "breathing space" and then give the shocks. He was conscious of becoming tense during the stimulation period.

In the record deeper and quicker breathing characterizes the period of stimulation but does not begin until the eighth inspiration after *b*. Nevertheless the O_2 line begins to rise immediately after *b*. The lower border of the abdominal tracing drops imme-

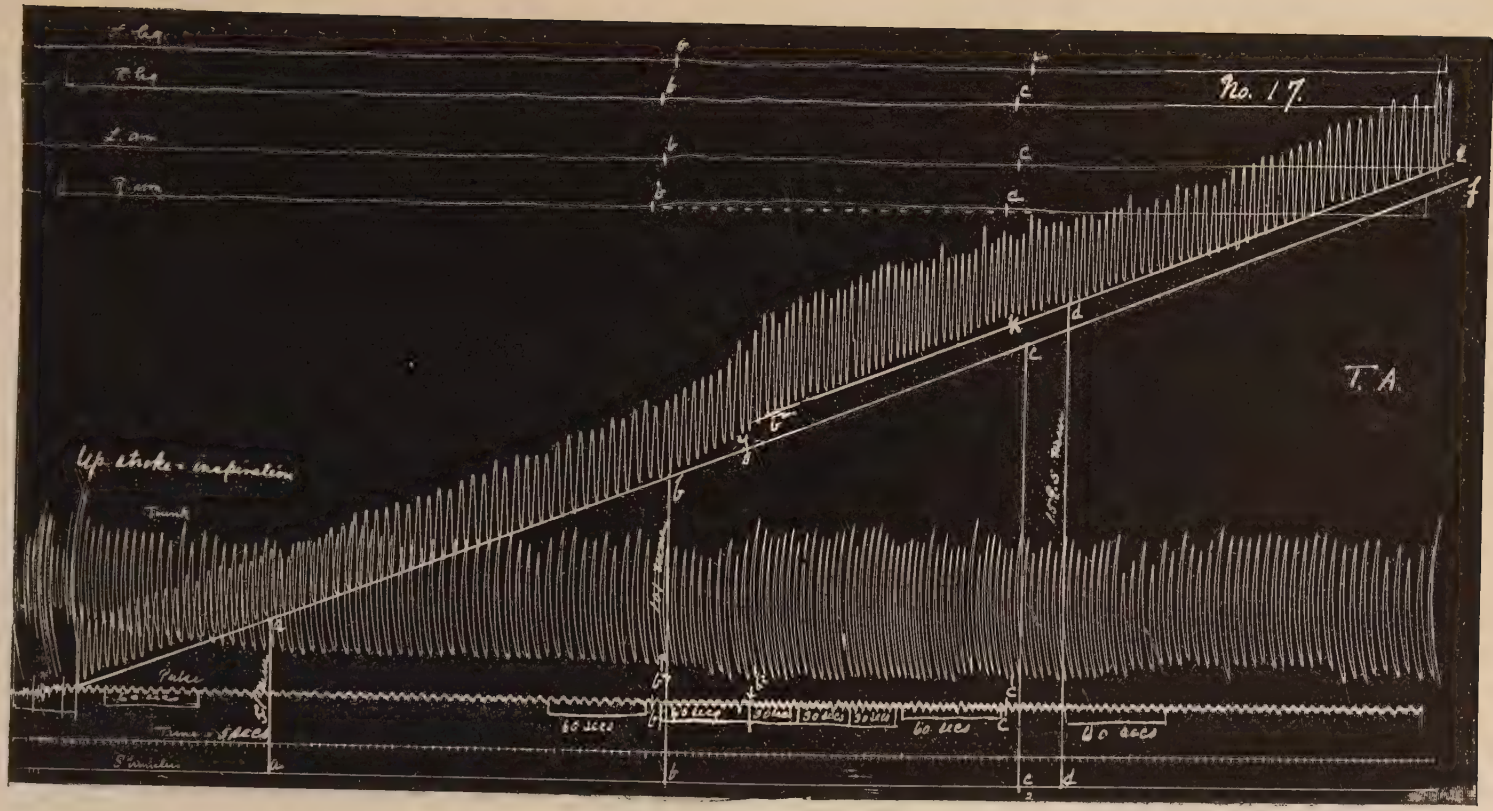
No. 17.
T. A.
Up. stroke - inspiration
Pulse
60 secs
30 secs
30 secs
60 secs
60 secs

Fig. 17

diately after *b* and resumes its original level only after *d*. The rise of the O_2 line above its original path continues to *x*, and at *x* the upper line begins to approach the lower. At *d*, however, it turns and continues parallel to the lower line and at a higher level to the end of the record.

Again there is the appearance of a real increase in the rate of oxygen consumption between *b* and *d*, an increase of 16.9 per cent. It is not to be explained as the result of continued deep breathing, since respiration returns to normal at *d*. In the absence of a thoracic tracing, it is not possible to state with certainty whether or not it is in part due to a continued expansion of the lungs, but the evidence of the abdominal tracing is against this. Almost certainly it could not be entirely due to this cause without making a definite change in the level of the abdominal tracing. If it is the result of increased oxygen consumption, however, its magnitude raises a doubt of its being due solely to internal changes and suggests that striped muscle activity may have been operative here. A comparison of this record with this subject's deep breathing records (figs. 6 and 7), will make it clear that the height of the O_2 line is not due to increased oxygen consumption resulting from the increased activity of the respiratory muscles.

The subject, however, reported being aware of becoming tense during the stimulation, and the possibility that the height of *d-e* above *c-f* is due to a real increase in oxygen consumption, resulting from other muscular activity, must be considered. As will be seen, the indications of tension in the arm and leg tracings are extremely slight. In order to get some idea of the effect of voluntarily tensing the muscles, in the absence of emotion, experiment 18 was tried. Here (fig. 18) at the signal "Begin," the subject voluntarily tensed the muscles of the whole body and maintained the tension till the signal "Relax" was given. The period of tension was from *b* to *c*. There was no way, of course, of prescribing accurately the amount of tension. The subject could only be told to become as tense as he thought he had been in the fake shock experiment. As a matter of fact he felt sure that the tension in no. 18 was greater than that in 17.

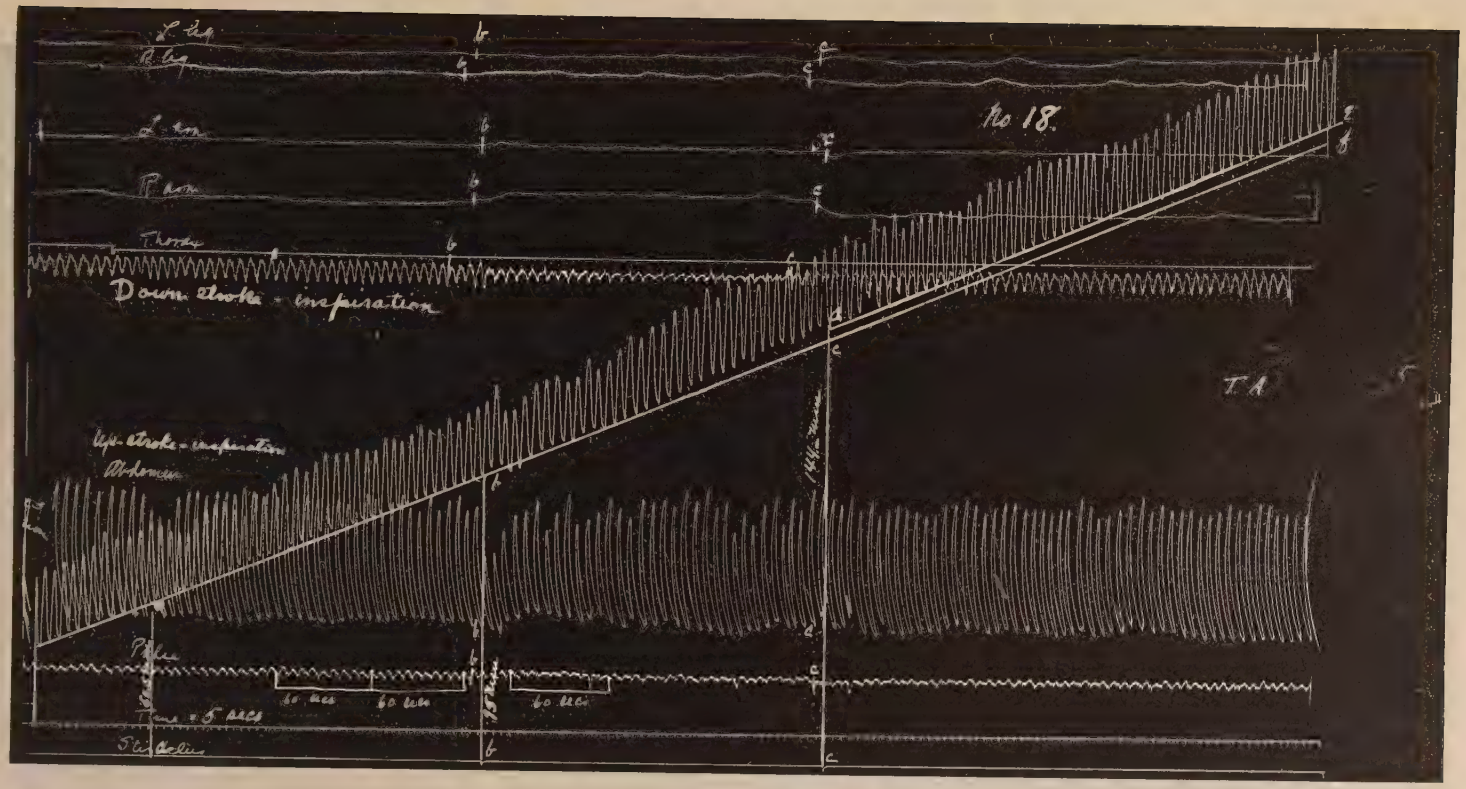
No 18.
Down stroke - inspiration
T 1
Pulse
Time = 5 secs
60 secs
60 secs
60 secs

FIG. 18

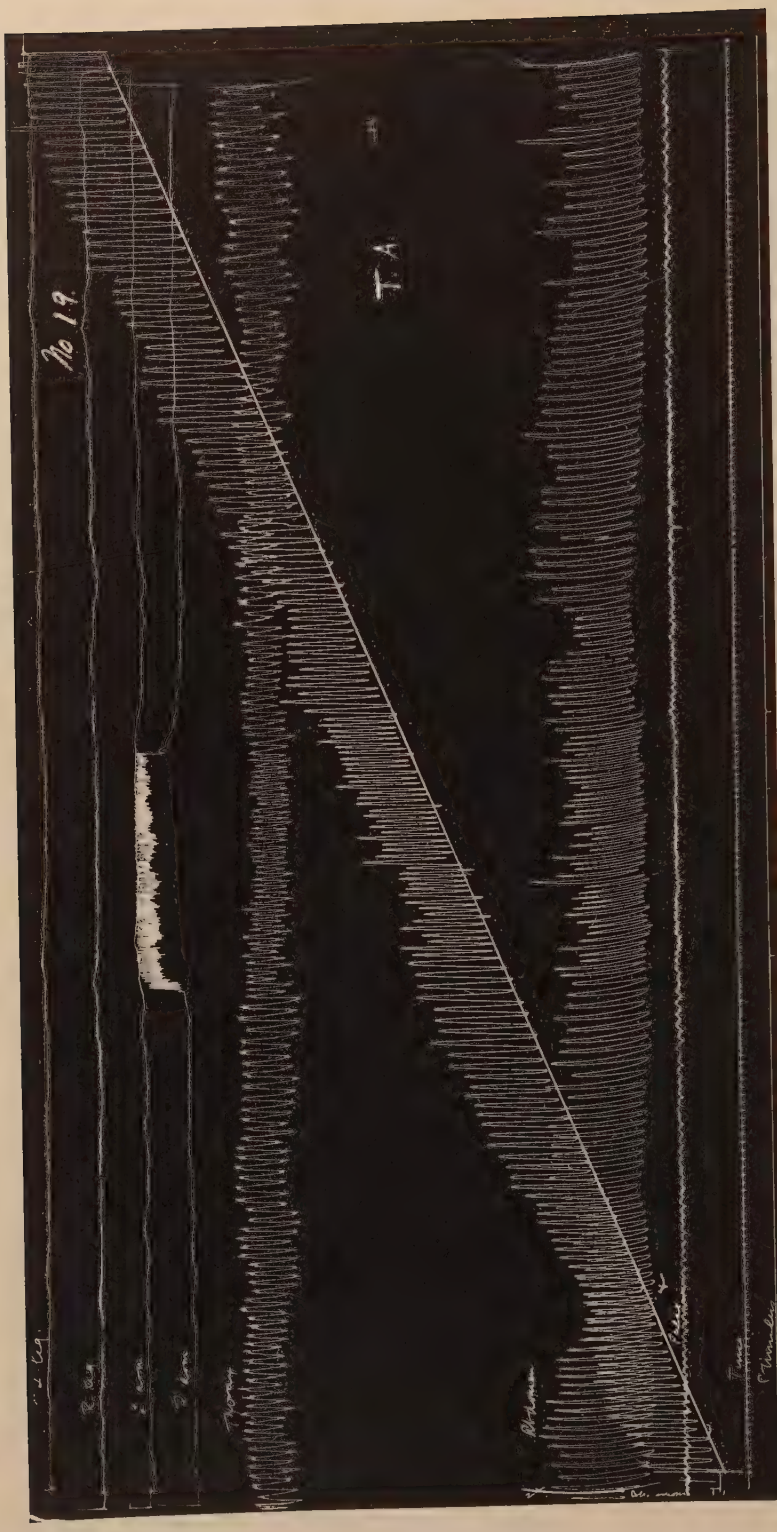

Fig. 19

The period of tension in 18 is 210 seconds, and the period of stimulation in 17 is 220 seconds. Nevertheless, the increase of oxygen consumption in 18 is only 10.2 per cent, while no. 17 indicates an increase of 16.9 per cent. Experiment 18 furnishes an inadequate check on no. 17, yet it makes it seem unlikely that much, if any, of the rise of the O_2 line in no. 17 is due to muscular tension. A considerable amount of muscular movement is possible with this subject without changing the level of the O_2 line. This is exemplified in experiment 19 (fig. 19)½ in which the subject pulled 10 kilograms on the dynamometer, once every second, for two and a half minutes. But again, since no measure of the muscular tension in no. 17 is possible, no. 19 is not an adequate check.

It seems then possible that we have in experiment 17 an increase in oxygen consumption, a part of which is due to increased functioning of internal organs, though how great a part this may be cannot be determined. There are, however, certain features of this record, which are repeated in experiments 20 and 23 (for which M. B. served as subject) and which suggest the possibility that, after all, the apparent increase in oxygen consumption indicated in the records is due to a dilatation of the bronchi and bronchioles as a result not of deep breathing but of the emotional stimulation itself, this dilatation continuing to the end of the experiment, and permitting the storing of a certain amount of oxygen.

I have already called attention to the fact that for seven breaths after *b* in figure 17, there is no increase in the depth of inspiration and yet the O_2 line rises steadily. It will be seen also that when the O_2 line drops to *d*, it returns almost exactly to the line in which it would have lain had there been no disturbance after the first seven breaths. This suggests to me the possibility that from *b* to *y* we may have the effect of a gradual dilatation of the bronchi and bronchioles, as a part of the total sympathetic response to the emotional stimulation; that the hyperpnea beginning at *y*, still further expanded the air passages, causing a further rise of the O_2 line; that with the subsidence of hyperpnea, the passages contracted somewhat, but that the direct effect of the emotional stimulation upon the bronchial

muscles continued to the end of the experiment; and that the height of *de* above *cf*, is due to the retention of oxygen in the enlarged dead space. The subject reported that he was conscious of no diminution of the subjective disturbance even after the buzzer stopped, and such a reaction as the dilatation of the bronchioles may well have been continued throughout the state of emotional disturbance.

In the next two records of emotion—figures 20 and 23, M. B.—there is the same rise of the O_2 line immediately after the beginning of stimulation with the delay of the onset of deep breathing. With the beginning of deeper breathing, there is again a further lift in the O_2 line. This additional height is, however, retained in these records throughout the after-period, since the deeper breathing beginning at *y* is continued through *de*. This persistence of the deeper, irregular breathing through the after-period would seem to indicate that the organism, with this subject, does not quickly return to normal after an emotional disturbance, although the subject did not report a persistence of the disturbed subjective state to the end of the experiment.

Nothing is known of the behavior of the bronchial muscles in emotion, and I suggest the theory outlined above, merely as a possibility. I think the features of experiments 17, 20 and 23 that have been pointed out, warrant an investigation at some time, with suitable methods, of the question whether the bronchial tubes do not expand or contract during emotion, and of the extent to which they are affected.

Probably the continued shallow breathing at the beginning of the stimulation period in experiments 17, 20 and 23 is the result of keen and expectant attention on the part of the subject to the stimulus. In nos. 17 and 20 the stimulus was the buzzer which to the subject indicated the immanance of a certain dreaded experience. In no. 23, as will be seen, the subject's attention was fixed upon certain sounds whose meaning was not at once understood. The consistent finding of students of respiratory movements during "mental" states has been that these movements become shallower during attention. This keen attention may well have delayed the onset of deeper breathing in these emotional periods.

The pulse count in the 60 seconds marked near the beginning of the fore-period of figure 17 is 54 beats; in the 60 seconds just before the beginning of stimulation, it is 55 beats. During the stimulation period: in the first 30 seconds marked off on the tracing, there are 34 beats; in the second, 50; in the third, 58; in the fourth, 54; in the fifth, 46; and in the last 60 seconds of the stimulation period there are 80 beats. Stating this record in terms of rate per minute, we have during the first minute and a half of stimulation 68 beats per minute, 100 per minute, and 116 per minute. This is followed by 108, 92, and 80 per minute for the rest of the stimulation period. In the sixty seconds marked off thirty seconds after the cessation of stimulation, there are 60 beats.

Experiment 20. Subject M. B. Temperature 21.5°–20.5°

The stimulus for this experiment was much the same as that of No. 18, but handled in a different way. At the first mark on the stimulus line (fig. 20), I said, "Now Miss B., I am going to use a stimulus for pain. I don't want to startle you, so I tell you that I shall apply the electrodes to your ears. Miss B. had already experienced the electric shocks of experiment 13, and knew how they felt and also what the buzzer meant. Immediately after speaking to her, I placed the electrodes against her ears and started the buzzer. At the second mark on the stimulus line, I stopped the buzzer. The subject shrank away visibly when the electrodes touched her. She said afterwards that she had been conscious of becoming tense and of relaxing after the buzzer stopped. At the third mark on the stimulus line, I asked her to relax and think of indifferent matters, but she said afterwards that she had already done so. She thought there was no change after I spoke. She was very conscious of the quickened beating of her heart.

The subject expected the shock as long as the buzzer sounded; once or twice for an instant she thought that she felt it, then realized she had not. She called the experience genuine dread. She expected the shock to be "dreadful," and was afraid it might make her deaf to have "a strong current so close to her brain."

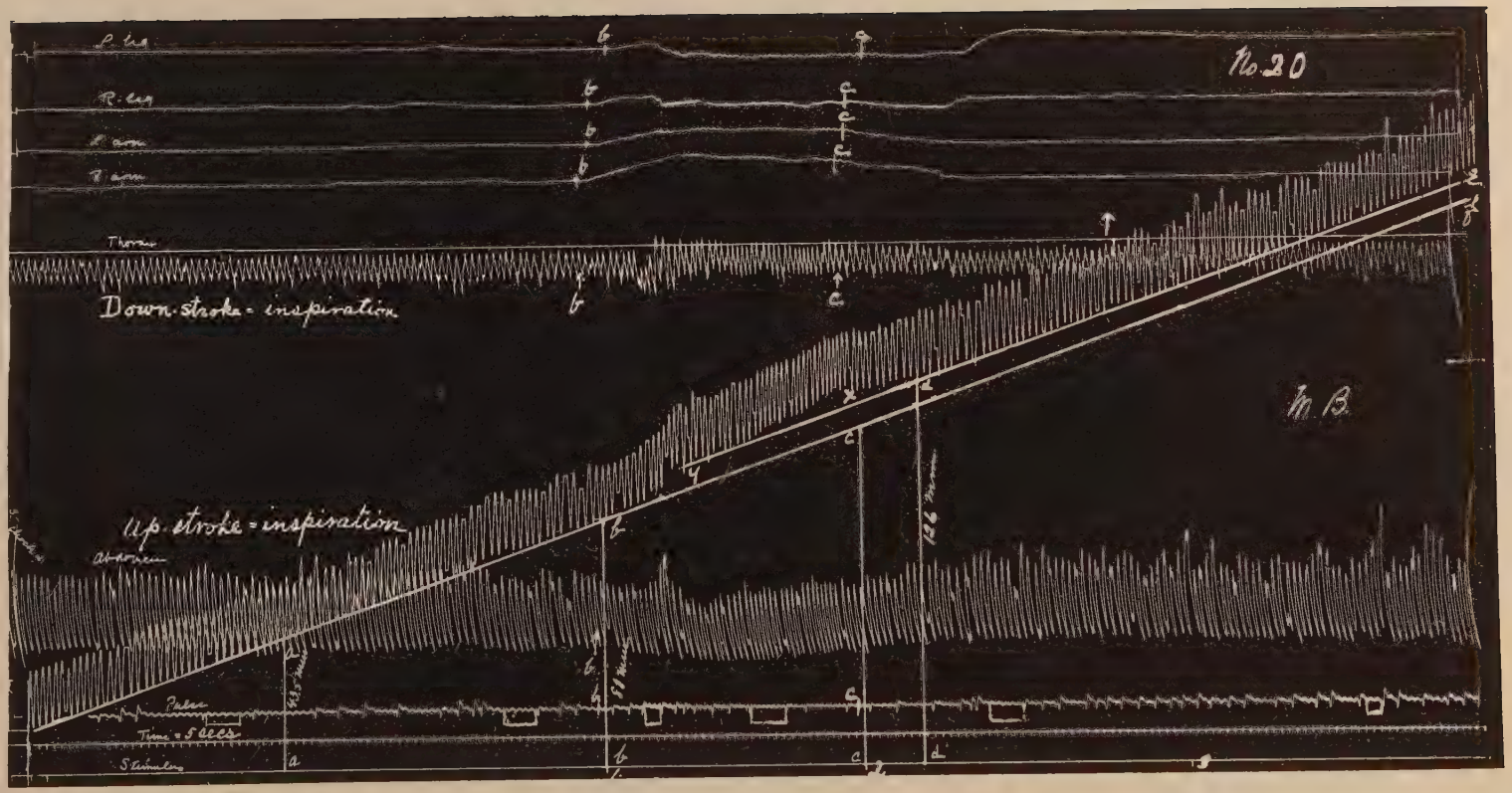
No. 20
Down. stroke = inspiration
Up. stroke = inspiration
M. B.
Pulse
Time = 5 secs.
Stimulus

Fig. 20

The O_2 line begins to rise immediately after *b* the point at which I began to speak, the rise being unaccompanied by deep breathing until *y* is reached. At *y* there is a brief period of deep breathing with a further lift of the O_2 line, which continues to rise above its original path as far as x, while respiration becomes shallower though quicker. At *d*, the O_2 line has returned to the same level that would have been reached had there been no disturbance after *y;* and respiration again becomes deeper and irregular as at *y*. From *d* to *e*, the upper O_2 line runs parallel to the lower one, at a higher level, and respiration continues irregular and deeper, as at *y* and *d*. In the height of *de* above *cf*, we have apparently an indication of an increase in the rate of oxygen consumption during *b-c*, an increase of 19 per cent. Undoubtedly part of the height of *de* above *cf* is due to the continued deeper breathing of the after-period. The same type of respiration may be seen in figure 26, beginning at *z*, and causing a lift of the O_2 line which is continued with the deeper breathing to the end of the tracing. However, the increase in depth of breathing in figure 20 is less than that in figure 26 and yet the height of the upper line above the lower in 20 is about twice that in 26. Evidently some other factor is at work in figure 20. Both the thoracic and the abdominal tracings show that expiration was not incomplete in the after-period. We must then consider the possibility that the apparent increase of 19 per cent in the rate of oxygen consumption is genuine, and consider whether it must be attributed to muscular tension or to internal organic change. Again the magnitude of the apparent increase raises a doubt of its being due to internal changes alone.

The subject reported having been conscious of becoming tense during stimulation and the tracings from the arms and legs show great disturbance. In interpreting these tracings, however, we meet the difficulty I have alluded to—that of distinguishing between the effect of volumetric changes and the effect of muscular tension. The leg tracings exhibit features which suggest strikingly those of plethysmographic tracings in disagreeable emotional states, i.e., a decrease in volume indicated by a drop in the level of the tracing and followed by a slow rise when a

relief from stress comes (10, 13; compare especially Lehmann, vol. I, experiment 40.)

But contraction of the extensor muscles of the legs, with a stretching out of the legs, would also give a fall in the line of tracing. So that the total effect in the record is possibly the result of both factors. The arm tracings indicate an increase in the size of the arms and, probably, therefore, show muscular contraction.

As in the case of subject T. A., an experiment was tried in which the effect of muscular tension alone was obtained. Figure 21 shows the effect of voluntary tension lasting from *b* to *c*. An increase of 22.9 per cent in rate of oxygen consumption resulted, the subject believing that tension here was greater than in the emotion experiments in which she made an effort to remain relaxed. As with subject T. A. considerable muscular movement is possible with this subject without changing the level of the O_2 line. Figure 22 shows the line unchanged by pulling 10 kilograms on the dynamometer once every two seconds for two and a half minutes.

It still remains impossible, however, to check up on the possible effect of muscular activity in no. 20, since the amount of activity cannot be measured either in no. 20 or in no. 21. Until some method of accomplishing such a measurement is devised, there seems to be no way of determining, in such cases as experiment 20, whether a change in oxygen consumption has resulted from muscular tension or not.

There remains also, the further possibility, as has been suggested, that a dilatation of the bronchial passages and the storing of oxygen in them may be the cause of the change in the level of the O_2 line.

The pulse record in figure 20 is much disturbed by frequent swallowing, and the rate must therefore be reckoned on the basis of rather brief periods. Two periods of 20 seconds each have been marked off in the fore-period, one of 10 seconds and one of 20 in the stimulation period, and one of 10 and one of 20 seconds in the after-period. The counts in these periods indicate a pulse varying from 75 to 72 beats per minute in the fore-period, rising

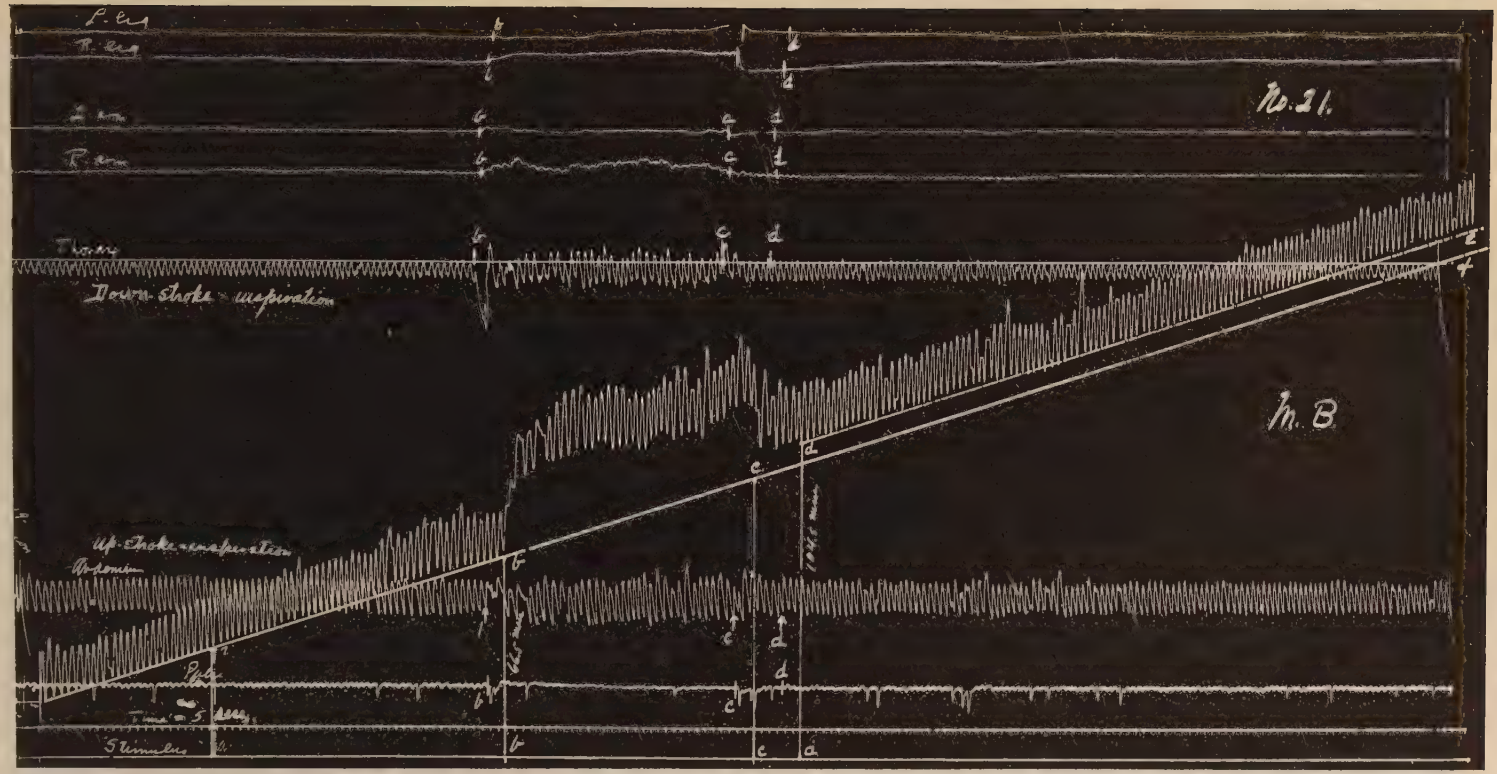
No. 21.
Down-stroke = inspiration
Up-stroke = expiration
Pulse
Time = 5 secs.
5 Seconds

Fig. 21

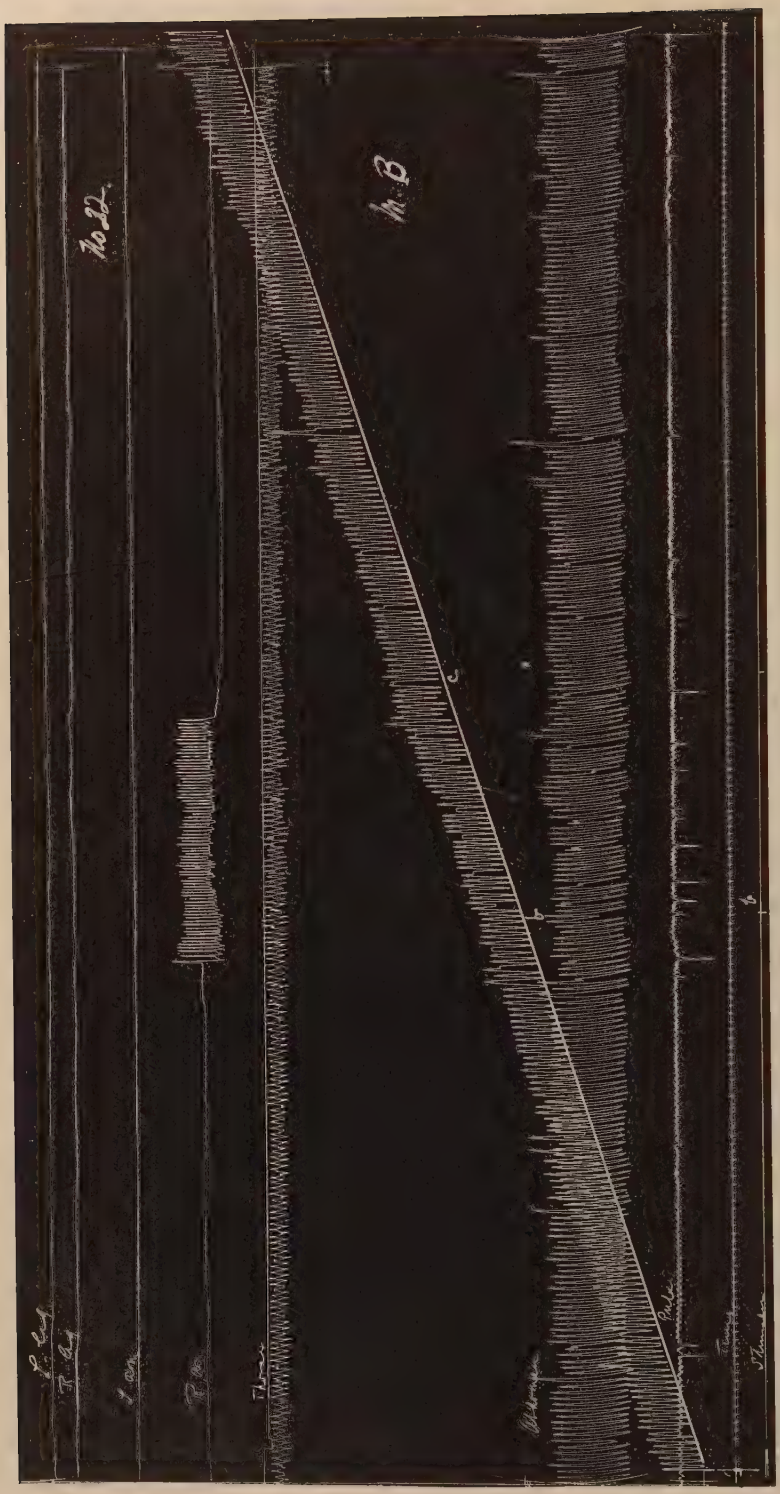

Fig. 22

to 120 beats per minute half a minute after the beginning of the stimulation; rising to 129 per minute ninty seconds after the beginning of stimulation, dropping to 84 per minute eighty seconds after the cessation of stimulation, and returning to the normal 72 per minute before the end of the experiment.

For the three following experiments, the procedure and records will be described, but a detailed interpretation will not be made since the same difficulties are present as in no. 20 and the same line of argument applies.

Experiment 23. Subject M. B. Temperature 25°–24°

M. B. is extremely fond of animals and is hypersensitive to the sight or sound of suffering in them. In this experiment I tried to use this characteristic. I procured a very young kitten and kept it outside the door during the early part of the experiment. At the first stimulus mark (fig. 23), I rose from my seat and said, "Please don't move or speak." I then went to the door and brought in the kitten. At the second mark I took off the blindfold, held the kitten where the subject could see it, and then laid it on her shoulder. At the third mark Dr. Dunlap came in, said, "That's no good," picked up the kitten and said, "If you pull its tail like this, it will cry like anything." From that point to the fourth mark, the kitten was kept crying pretty continuously. It was really handled gently and not hurt; but being young and not having been away from its mother before, it cried at the slightest touch. At the fourth mark the kitten was removed and the blindfold replaced.

After freeing the subject from the apparatus. I said, "Did that disturb you?" "It certainly did" was the answer. "I wouldn't have come if I had known you were going to pull little kittens' tails. I think it was cruel." She said she was very much disturbed by the kitten's cries, but less so than she would have been if she had not believed that Dr. Dunlap was not really a brutal person. Also she thought that the realization that this was being done in order to disturb her affected her reaction.

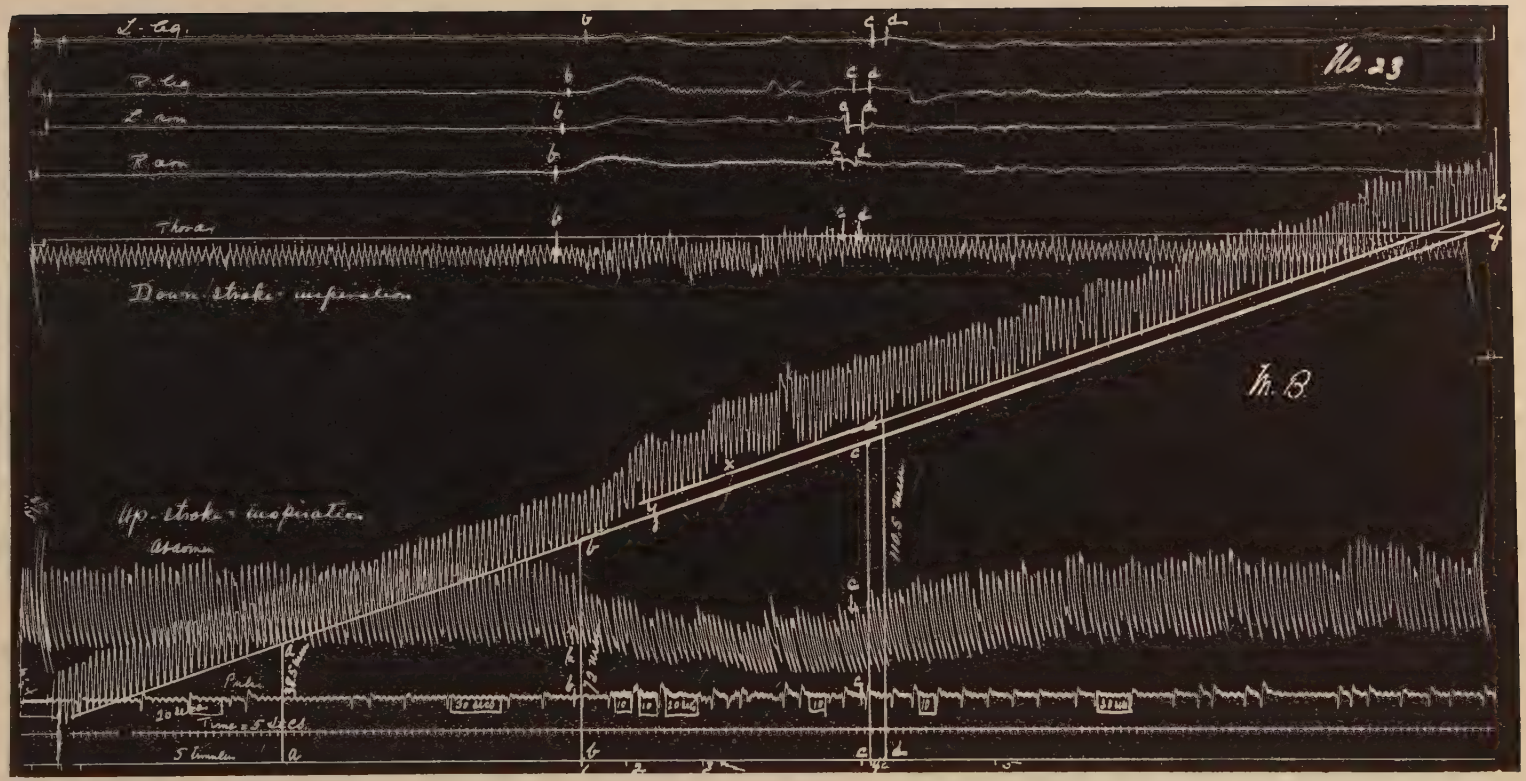
L. leg.
R. leg
L arm
R arm
Thorax
Down-stroke - inspiration
Up-stroke - inspiration
Abdomen
Pulse
Time 5 sec.
5 minutes
No 23
M. B.

Fig. 23

She remembered wondering if I was "getting anything." When I cautioned her not to move and went to the door, she thought I was going to do "something dreadful." It just happened that, as I opened the door, a man's voice and footsteps were heard in the hall, giving her the idea that I was having "something big" brought in, and she became much "excited." Here her attitude was evidently one of keen attention to the sounds in the hall as well as one of excitement.

In this record as in the two preceding, there is shallower breathing for a few inspirations immediately after *b*, with a slow lift of the O_2 line, then a sudden deepening of respiration at *y*, with a continuance of the deeper, irregular breathing and the higher level of the O_2 line to *e*. Also marked disturbance appears in the arm and leg tracings which, as in figure 20, probably indicates both volumetric and muscular changes.

The continued height of the O_2 line from *y* to *e* indicates, if taken at its face value, an increase in the rate of oxygen consumption of 14.9 per cent. A part of the height of the line must be attributed to the deep breathing of the after-period. For the rest, there are the possibilities that it indicates either dilatation of the bronchi and bronchioles due to emotion, or a genuine increase in oxygen consumption. If the latter, it remains a question whether the height of the line is entirely due to muscular tension or not.

The pulse shows a rate of 64 beats per minute in the fore-period, 102 per minute in the first forty-five seconds after the beginning of stimulation, with a drop to 84 per minute immediately afterwards, and increasing again to 102 per minute twenty seconds before the end of stimulation. This experiment must be looked upon as involving a double stimulation, first the sounds at the door which the subject feared presaged "something dreadful," and then the distress of the kitten. Doubtless the two high points in the pulse rate are the result of this fact. Thirty-five seconds after the cessation of stimulation, the pulse has dropped to 78 per minute; and two and a half minutes after the cessation of stimulation, to 66 per minute.

Experiment 24. Subject M. B. Temperature 23.5°–23.5°

The stimulus was a white rat placed on the subject and allowed to crawl about over her. The subject had seen the rat before and knew that I had more than once been bitten by it. At the first mark on the stimulus line (fig. 24), I moved from my seat and said, "Now Miss B., please don't move or speak, whatever happens." Then I opened the box containing the rat and as I did so, drew in my breath quickly and audibly, as if in pain. There was a pause and again I drew in my breath, and then uttered a suppressed "oh." Then I picked up the rat, which squeaked as I did so, allowed the subject to look at it and then put it down on her shoulder close to her cheek. It nosed about a while, sniffing and finally crawled under the blanket and lay down. At the second mark I removed it and replaced the blindfold.

The subject reported that, when I told her not to move or speak, she experienced keen excitement. The rat's squeak told her what I was about to do. She believed from my exclamations that it had bitten me and wondered if it would bite her. She did not think that fear was what she experienced, but she said there was "considerable emotional disturbance" though she could not find a name for it. She thought the emotional disturbance was more pronounced before the rat was put on her than afterwards.

While the rat was sitting on her chest, I saw signs of some movement on her part, though the blanket stretched over her prevented me from seeing just what happened. She reported that, when I removed the rat, she felt her left leg move as if it had dropped back into place after being raised.

The record shows shallower breathing from *b* to *y* and the O_2 line rising from its original path. Then at *y*, the sudden change to deeper breathing, which is characteristic of this subject's records, occurs and continues to the end of the tracing with the O_2 line from *d* to *e* parallel to *cf* and well above it, indicating an increase in the rate of oxygen consumption of 25 per cent during *b-c* or possibly a retention of oxygen in an enlarged dead space.

Again the characteristic changes occur in the arm and leg

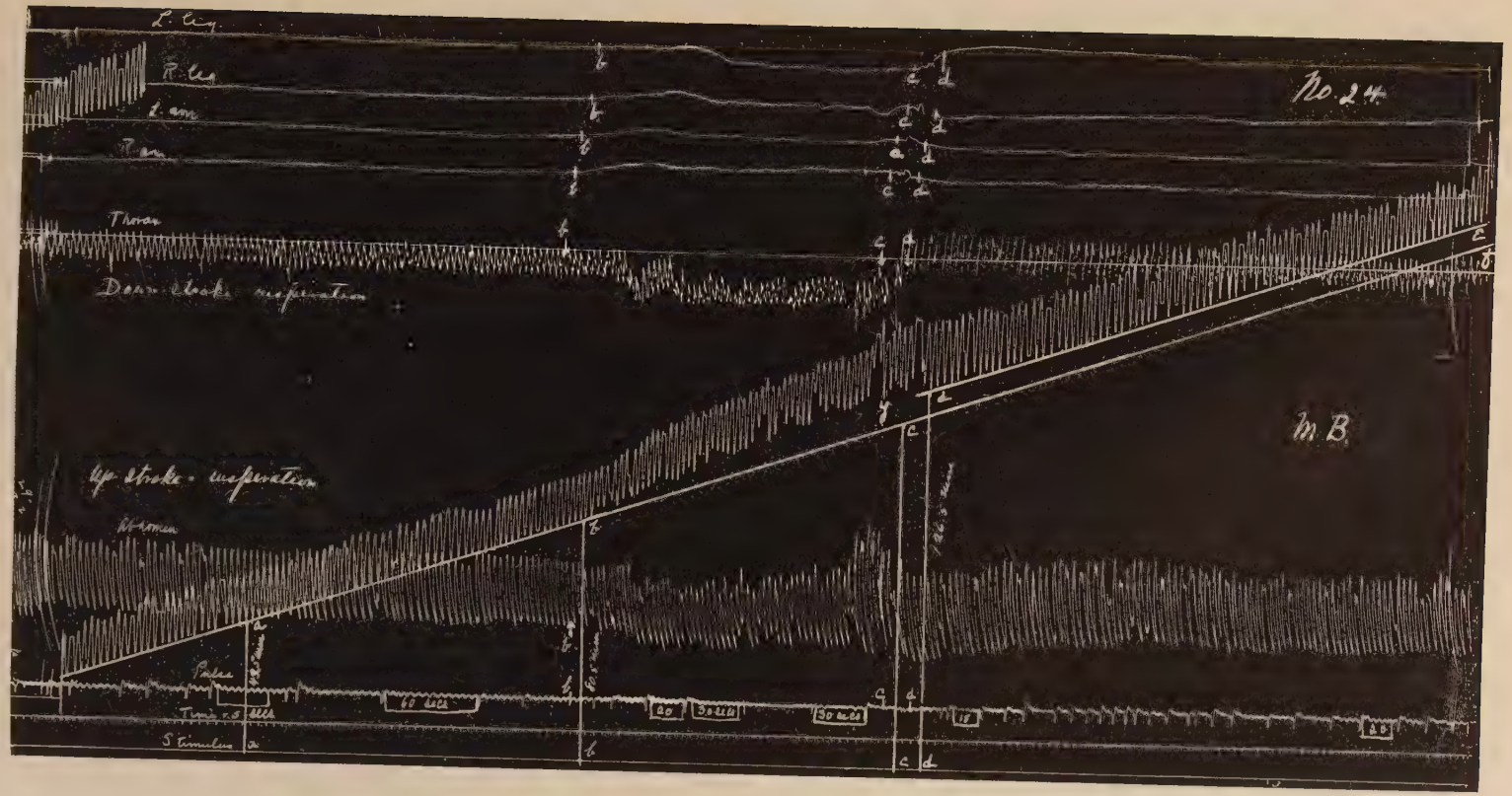
No. 24.
M B.
Down stroke = inspiration
Up stroke = inspiration
Thorax
Pulse
Time
Stimulus

Fig. 24

tracings, and in addition we have a decided displacement of the thoracic and abdominal tracings indicating tensions of the body muscles.

The pulse changes, based on the count of beats in the portions of the tracings that have been marked off in the record, are: 58 beats per minute in the fore-period; 99 per minute about a minute after the beginning of stimulation, 82 beats seventy-five seconds after the beginning of stimulation, and 80 beats in the last minute of stimulation; 68 per minute thirty-five seconds after the removal of the stimulus, and 63 per minute five minutes after its removal.

Experiment 25. Subject M. B. Temperature 21.5°–20.5°

For this experiment an earth worm was allowed to squirm over the subject's face and neck. At the first stimulus mark (fig. 25), I moved to get the worm. At the second, I removed the blindfold and held the worm so that the subject could see it. I then dropped it on her face. It wriggled on her face, then squirmed up through her hair, and finally dropped to her neck where it remained till I removed it at the third mark.

The subject said: "I didn't like it. My first reaction was amusement, but I didn't realize that you were going to put it on me. It was something like disgust, but not very pronounced. It was unpleasant, but I could endure it. It was more unpleasant than the rat, but not so exciting." She objected to it most when it was in her hair and neck, and felt that she was "holding on" to herself in order to endure it. She felt quite sure that she stiffened, but that she relaxed and was perfectly comfortable before the experiment was at an end, though not immediately after the worm was removed.

During the first part of the stimulation period, the record shows the effect of the subject's tendency to laugh in the forced expirations that bring the curve down below the O_2 line at several points. At *y* there is the usual sudden deeper breathing with a lift of the O_2 line. At *d* the line drops suddenly but not to its original path, and *de* continues above *cf* to the end. The rise of

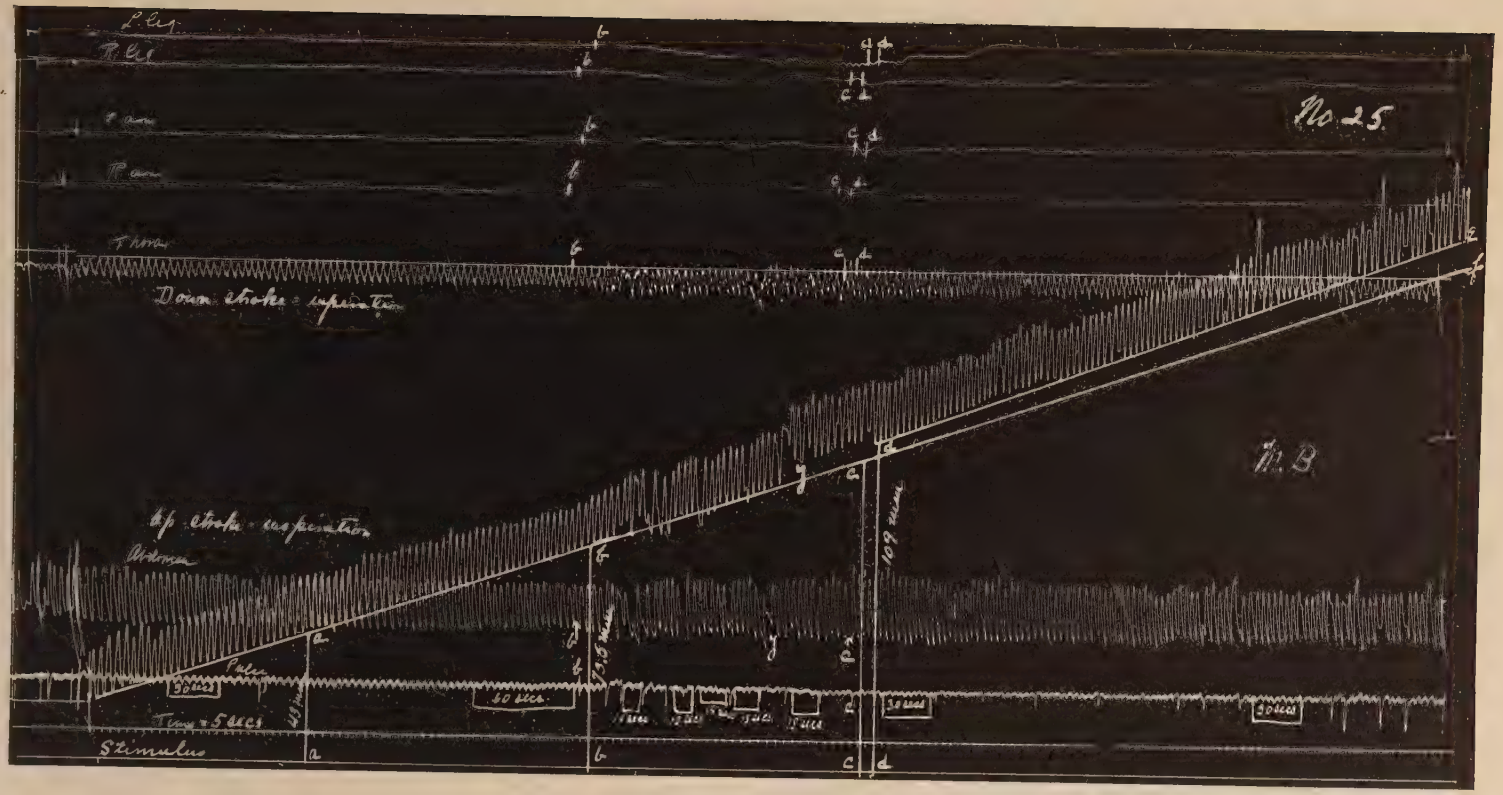
No 25.
Down stroke = inspiration
Up stroke = inspiration
Abdomen
Pulse
Time = 5 secs
Stimulus
109 mm
73.5 mm
30 secs
60 secs

FIG. 25

de at a slightly greater angle than *cf*, indicates that metabolism is proceeding at a higher rate than normal, during the afterperiod.

The apparent increase in rate of oxygen consumption during *b-d* is 16 per cent, and since respiration during the afterperiod is virtually of normal-depth, the level of the O_2 line is not to be attributed to deep breathing.

Indications of muscular tension are clear. Although the record does not show the features during the period of stimulation, which in figures 17, 20 and 23 suggested dilatation of the air passages, nevertheless it is equally possible that dilatation has occurred here, while its early manifestation has been masked by irregularities of respiration.

The pulse shows 62 to 66 beats per minute before stimulation; 84 per minute during the first minute after stimulation, 76 per minute seventy seconds after the beginning of stimulation, 72 per minute ninty seconds after the beginning of stimulation, 72 per minute fifteen seconds before the end of stimulation; 70 beats per minute fifteen seconds after the cessation of stimulation and 66 per minute four and a half minutes after the cessation of stimulation.

Experiment 26. Subject M. B. Temperature 25°–23.5°

In experiment 26, stimulation of quite another sort was used with complete success as far as M. B.'s subjective experience was concerned, but with objective results whose interpretation can only be suggested.

Before the experiment, I told the subject that I was not going to perform an experiment that morning because Dr. Dunlap was coming in to look over the recorders. At the first mark on the stimulus line (fig. 26), Dr. Dunlap entered the room. He came over to the apparatus and stood beside me, then said, "Why look at that, has it been like that all the time?" I said, "Yes." He then pointed out two or three other levers saying they were entirely wrong, that it was no wonder my results had been so ambiguous, and more to the same effect. My remark, "If you had only seen it sooner," brought forth the answer that he was

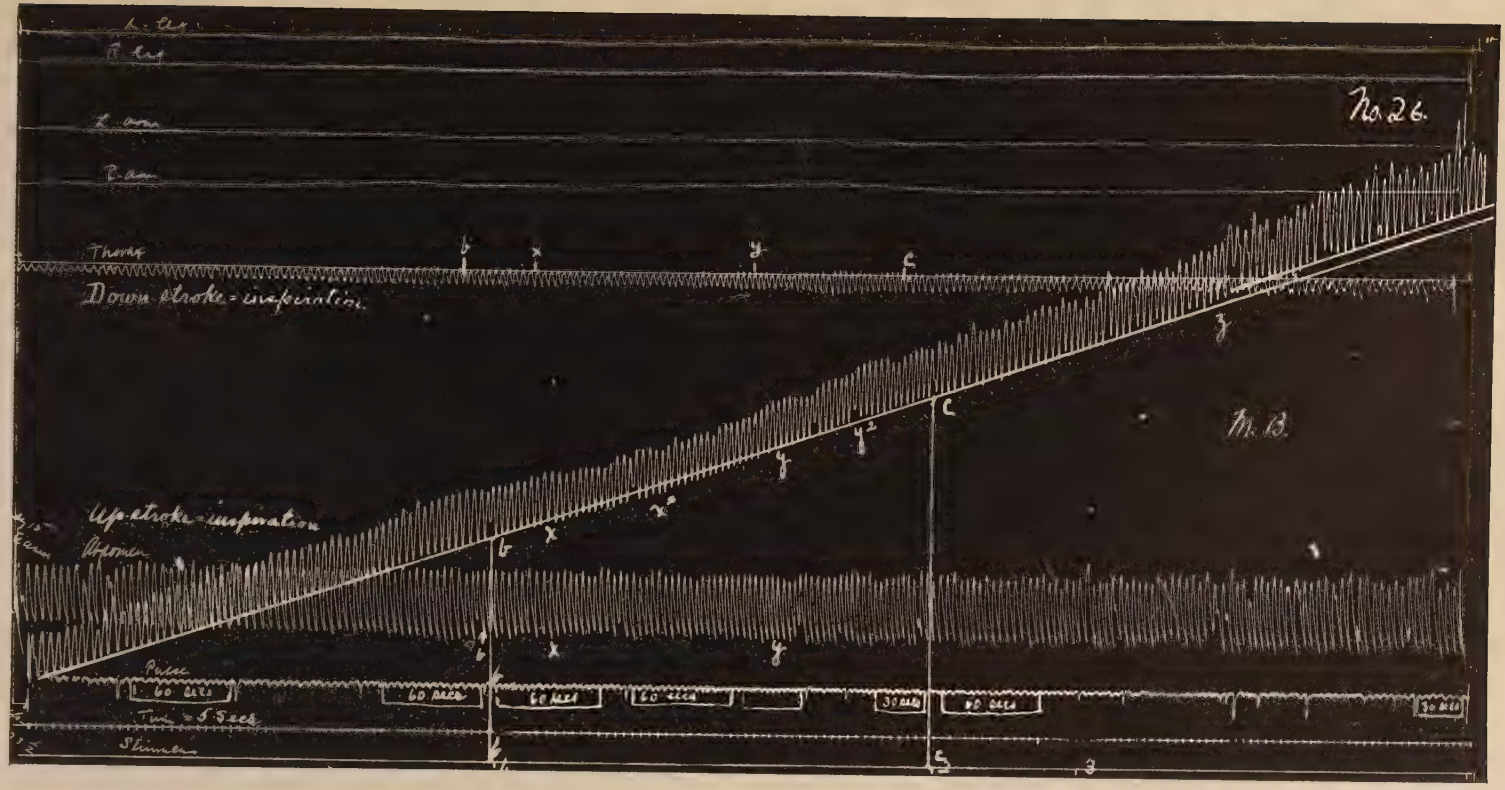
No 26.
Thorax
Down stroke = inspiration
Up stroke = inspiration
Abdomen
M. B.
Pulse
Time = 5 Secs
Stimulus

FIG. 26

sorry he had not watched my work more carefully, but that almost any one ought to be able to handle such simple matters of technique alone; and that of course, all the work I had done was entirely without value. I expressed utter despair in a voice I succeeded in making tremble. At the second mark on the stimulus line, Dr. Dunlap left the room and at the third, I explained to the subject that the conversation was a hoax for her benefit.

The subject's report was: "Oh, I thought it was awful. I thought you had begun to cry. I couldn't understand how Dr. Dunlap could be so brutal. I wanted to put my arms around you. It made me feel as though I wanted to weep. I haven't got over it yet." When I explained the nature of the episode at (3) she was "thankful at first and awfully relieved; then I kept thinking how I had felt about it."

The record shows an effect wholly different from any others. From *b* to *c* is the total period during which the conversation lasted. Soon after *b*, at *x*, respiration becomes notably shallower, probably the effect of close attention to what was being said, and the O_2 line sinks gradually below its original level. At x^2 it takes an upward trend and at *y* reaches its original path, continuing from *y* to *z* at the original level and angle. From *x* to *y* on the thoracic and abdominal tracings there is the record of diminished amplitude both of inspiratory and expiratory movements. Clearly, then, the drop of the O_2 line is not due to deeper exhalations and a consequent forcing out of an extra amount of oxygen at each expiration. Is it to be interpreted as showing a reduced rate of oxygen consumption from *x* to x^2 with an increased rate from x^2 to *y*, the latter just balancing the former? It seems to me extremely unlikely, and I should not be disposed to accept that explanation until another possibility has been investigated, i.e., that we may have here a gradual contraction of the walls of the bronchi and bronchioles and a consequent squeezing out of oxygen, followed by the return of the air passages to their normal size. This change is to be conceived as a part of the reaction pattern resulting from the stimulation and characteristic of the emotion of pity. This is a point to be dealt with by investigation adapted specially to it, with other methods than are used here.

The pulse changes, reckoned from the portions of the tracing that are marked off, are: for the foreperiod, 64 beats per minute to 74 beats per minute; for the stimulation period, 65, 69, 82, and 82 beats per minute; for the after period, 73 to 70 beats per minute. The striking increase of pulse rate just before the beginning of stimulation is doubtless to be explained by the fact that, as Dr. Dunlap stood at the door waiting for my signal, he inadvertently made a sound which the subject told me afterwards she had heard. In this experiment we have a slow rise of the pulse rate through two and a half minutes of the stimulation period, with the maximum rate maintained thereafter to the end of the stimulation period. The pulse changes bear no relation to the changes in the O_2 line.

Experiment 27. Subject M. K. Temperature 23.5°–22.5°

The stimulus used in this experiment was the same as that used for subject T. A. in no. 17. Three days before, the subject had been subjected to a series of electric shocks, the effect of which has been shown in figure 14. In the earlier experiment the buzzer had been sounded while the electric shocks were being given and also for 30 seconds before the first shock. In the present experiment the buzzer was sounded alone.

At *b* (fig. 27), I moved to the electrical apparatus, started the buzzer about seven seconds later, and let it continue to *c*, when it was silenced. On releasing M. K. from the apparatus, I led her to believe that I had intended to repeat experiment 14, but that the apparatus had not worked; and got her report of the experience without betraying my real purpose.

She said she was not frightened. "But I was frightfully nervous. It was an awful feeling, thinking it was coming." "I don't know just what you would call it but it was quite bad. I think it amounts to real dread." She said that while it was going on, it occurred to her that perhaps I was trying to mislead her in order to make her anxious, but the thought did not reassure her. She tried not to become tense, but could not help it. For a little while after the buzzer stopped, she thought I might begin again; but she then became reassured, and thought she became entirely quiet and relaxed.

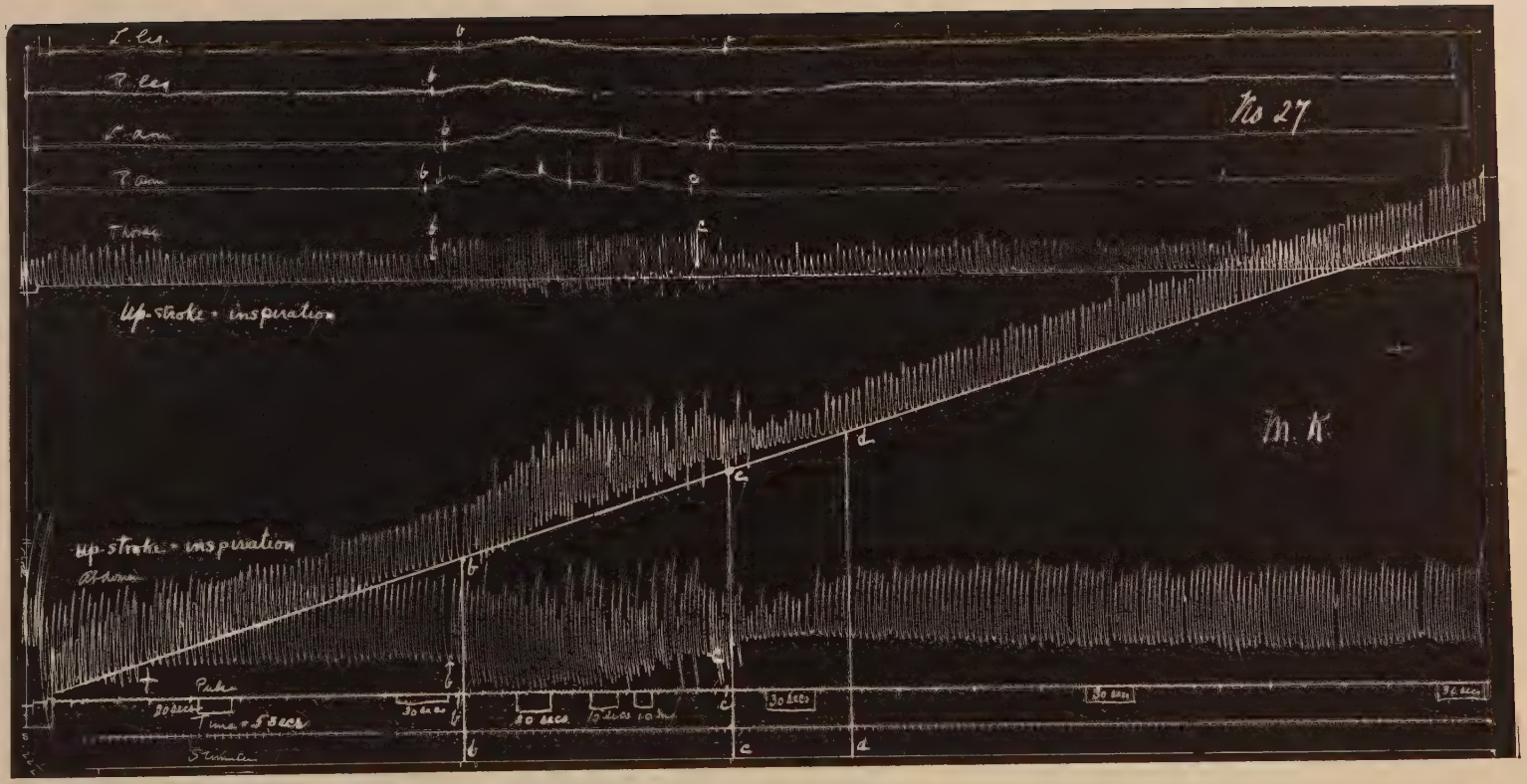
No 27
M. K.
up-stroke = inspiration
up-stroke = inspiration
Pulse
Time = 5 secs
30 secs
30 secs
30 secs
30 secs
30 secs
30 secs
b
c
d

FIG. 27

The record shows regular breathing until after I moved at *b*. Between *b* and *c* respiration becomes decidedly deeper and quicker and very irregular. From *c* to *d* it continues irregular, but becomes shallower at *d*, resumes its normal depth and rate, continuing thus to the end of the record. During the hyperpnea of *b*-*c*, the O_2 line rises characteristically. From *c* to *d* it proceeds at an angle less than the fore-period *a*-*b*, and at *d* resumes the angle and level of the fore-period. The thoracic and abdominal tracings show less expansion of chest and abdomen at the end of expiration between *b* and *c* than before *b*. We have then, evidently, an example merely of the effect of hyperpnea. Since beyond *d* the O_2 line resumes the level as well as the slope of the fore-period, there has been no increase in the rate of oxygen consumption during the period of stimulation, although the emotional state was genuine and by no means mild. The tracings from the arms and legs, as well as the subject's report, show considerable tension and movement, but evidently not enough to increase oxidation to a degree that could be measured by this method.

The pulse record during the period of stimulation is much broken by frequent swallowing, but the pulse may be counted for the periods marked off on the tracing. The period of twenty seconds and the later period of thirty seconds indicate a rate of 84 per minute for the fore-period. In the first minute after stimulation the rate increases to 135 per minute; seventy-five seconds after the beginning of stimulation, it is 124 per minute; and one hundred seconds after stimulation, it is 108 per minute. Twenty-five seconds after the cessation of stimulation, it has fallen to 80 per second and keeps this rate to the end of the experiment.

Experiment 28. Subject M. K. Temperature 22.5°–21.5°

This record shows the effect of dread with a stimulus of much the same sort as in no. 27, but handled in a different manner and continued for four minutes. This experiment was performed four weeks after no. 27. At the first mark on the stimulus line (fig. 28), corresponding with *b* on the tracings, I said, "Miss K., I am going to use a stimulus for pain. I don't want to startle

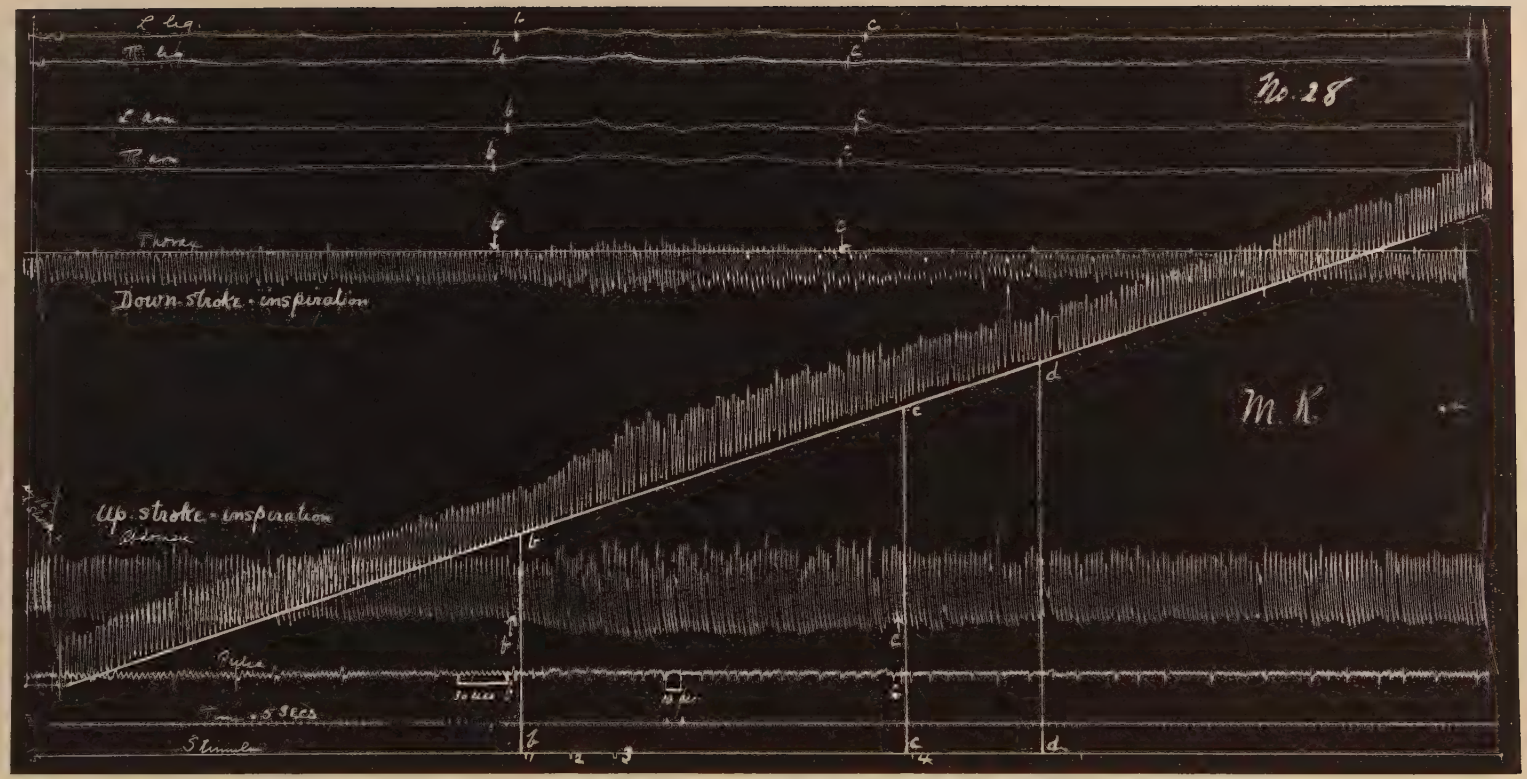

FIG. 28

you, so I tell you that I shall apply the electrodes to your ears. Please hold perfectly still as long as you possibly can." At the second stimulus mark, I placed the electrodes; and at the third, started the buzzer, stopping it at the fourth mark which corresponds with *c* on the tracings.

The subject's report was: "Yes, I hated it. I'm an awful coward. It was dread. It was awful, anticipating it. Then, when you pressed the electrodes tighter and I thought I was getting a shock, and it was so mild, I was relieved. I hate electric currents." Of course no shock was given, and when the buzzer stopped she ceased to expect one. The point at which I pressed the electrodes closer and at which she "felt relieved" was some time after the buzzer was started, but apparently either I neglected to press the button for the stimulus recorder or I did not press it hard enough to move the pointer.

The disturbance of breathing is less here than in figure 27. Breathing is deepened between *b* and *c*, but not to a great extent, and the lift of the O_2 line is correspondingly slight. At *d*, respiration returns to the normal rate and depth, and the O_2 line resumes its normal slope and level. Again there is no indication of a change in rate of oxygen consumption during the period of emotional disturbance.

The tracings from the arms and legs show changes in muscular tension, though less than in figure 27.

The pulse record is very unsatisfactory; but, basing the estimates on the 30 second period marked off to the left of *b* and on the 10 second period marked off to the right of *b*, the rate before stimulation was about 70 per minute. It reached 102 per minute during stimulation.

Experiment 29. Subject M. K. Temperature 21.5°–20°

The stimulus for no. 29 was an angle worm placed on the subject's face and allowed to squirm about, making its way up under her hair and then dropping to her neck and crawling under her clothing.

At the first stimulus mark (fig. 29), I rose and reached for the worm. At the second, I removed the blind-fold from the

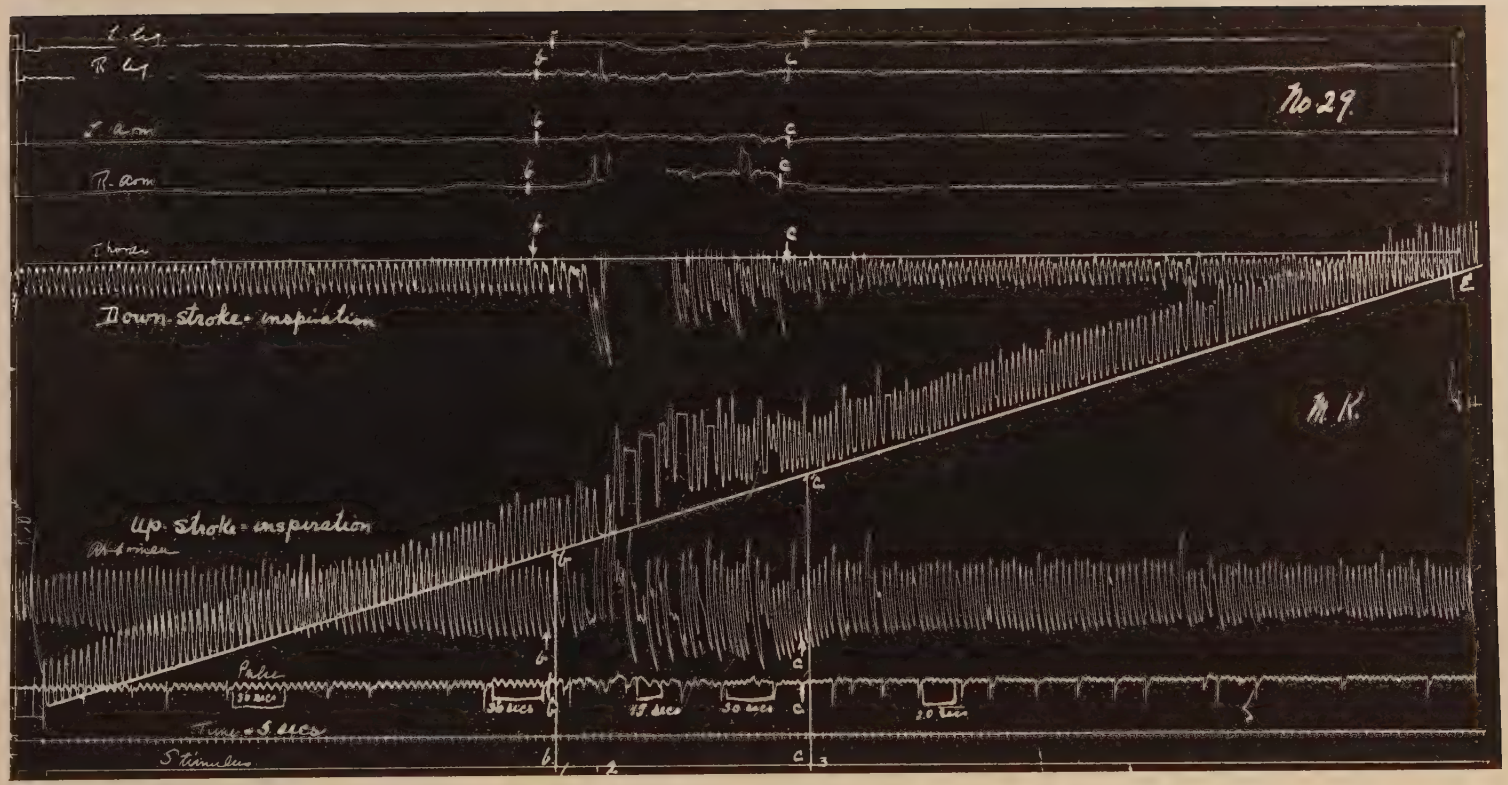
No 29
Down-stroke = inspiration
M. K.
Up-stroke = inspiration
Pulse
30 secs
30 secs
15 secs
30 secs
2.0 secs
Time = 5 secs
Stimulus

FIG. 29

subject's eyes and held the wriggling worm so that she could see it. I then laid it across her face. At the third mark, I removed it.

The subject's report was: "Yes, I hated that. I hated to look at it almost more than having it on me. It's the horror of the slippery thing. It was worst at first. Afterwards, I found I could stand it, but I didn't like it then." The worm was on the subject for two minutes thirty-five seconds.

Respiration becomes deeper and uneven after the point at which the worm was shown to the subject. The O_2 line rises, drops before reaching *c*, and beyond *c* continues about a millimeter and a half above the original level. Inspection of the thoracic tracing shows, apparently, an expansion of the lungs continued from *c* to *e*, as indicated by the fact that the upper border of the tracing from *c* to *e* fails to touch the horizontal line above it, except at a few points, while before *b* it is practically in continuous contact with it. This continued incomplete expiration is possibly the explanation of the very slight divergence of the spirometer tracing from the original O_2 line after the emotional disturbance. But supposing this divergence to indicate an increase of oxygen consumption, the very pronounced indications of muscular movement shown in the arm and leg tracings, and also apparent to my observation, would make it impossible to attribute the increase to anything but striped muscle activity. If there were any way of measuring the amount of the muscular activity, it would be possible to reproduce it without emotion and so check these results. Unfortunately this cannot be done.

The pulse is too indistinct to be counted with accuracy, but the changes appear to be slight. The rate increases from 80 per minute to about 88 per minute during the fore-period. At the end of the first minute of stimulation, it is still about 88. It drops to 84 at the end of the second minute of stimulation and to 81 a minute and a half after the end of stimulation.

Experiment 30. Subject M. K. Temperature 22.5°–20.5°

The stimulus used in no. 30 was the same as for 29, except that two worms were used instead of one. At the first mark on the

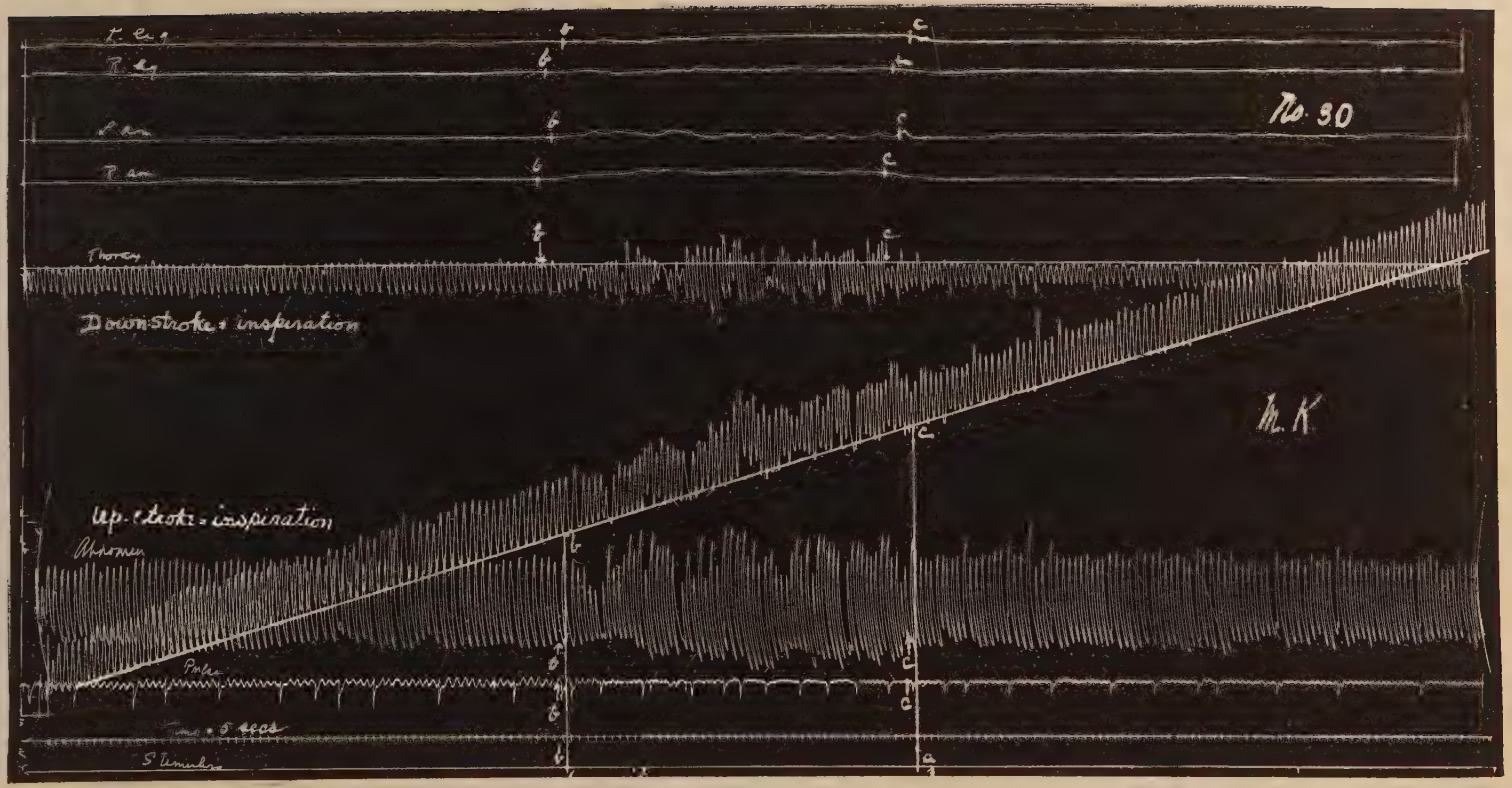
No. 30
Down-stroke = inspiration
M. K
Up-stroke = inspiration
Abdomen
Pulse
Time = 5 secs
Stimulus

FIG. 30

stimulus line (fig. 30). I moved to take up the worms; and, between the first and second mark, I said, "Now, Miss K., no matter what I do, please try to remain relaxed." At the second mark, I removed the blind-fold, holding the worms before the subject's eyes and then laying them across her face. They squirmed about in her hair, over her face and neck. At the third mark, I removed them. The stimulation period was 3 minutes 37 seconds.

The subject reported that the experience had been more disagreeable this time than on the first occasion four days before. She called the reaction "repugnance." "I just hate the slippery things." She was conscious of becoming tense, though she tried to avoid it.

Respiration becomes very irregular between *b* and *c*, with somewhat deeper inspirations and very much forced expirations. At *c* it returns to normal, and the O_2 line continues at its original angle and level, thus giving no indication of a change in the rate of oxygen consumption during the emotional disturbance.

The pulse is too indistinct to be counted.

Experiment 31. Subject V. D. Temperature 25°–24.5°

The procedure for this experiment was as follows: The door of the room was left ajar, and, at the time previously arranged, the secretary of the psychology department came quietly to the door and waited for my signal. When I nodded, she knocked. I went to the door, going out and closing it behind me. Almost immediately I returned to the apparatus and said, "Mrs. D., Miss H. has had a telephone message from Mr. D. asking you to come home as soon as you have finished with me." The knock at the door came at the first mark on the stimulus line (fig. 31), and I began to deliver the message at the second mark.

The subject reported that she had accepted the message without any misgivings and had been very much frightened, thinking that something must have happened to an elderly member of her family who was in bad health. Sometime later she realized that I was not giving any stimulus, and thinking then that the message might be a hoax, she decided that it was not worth while to

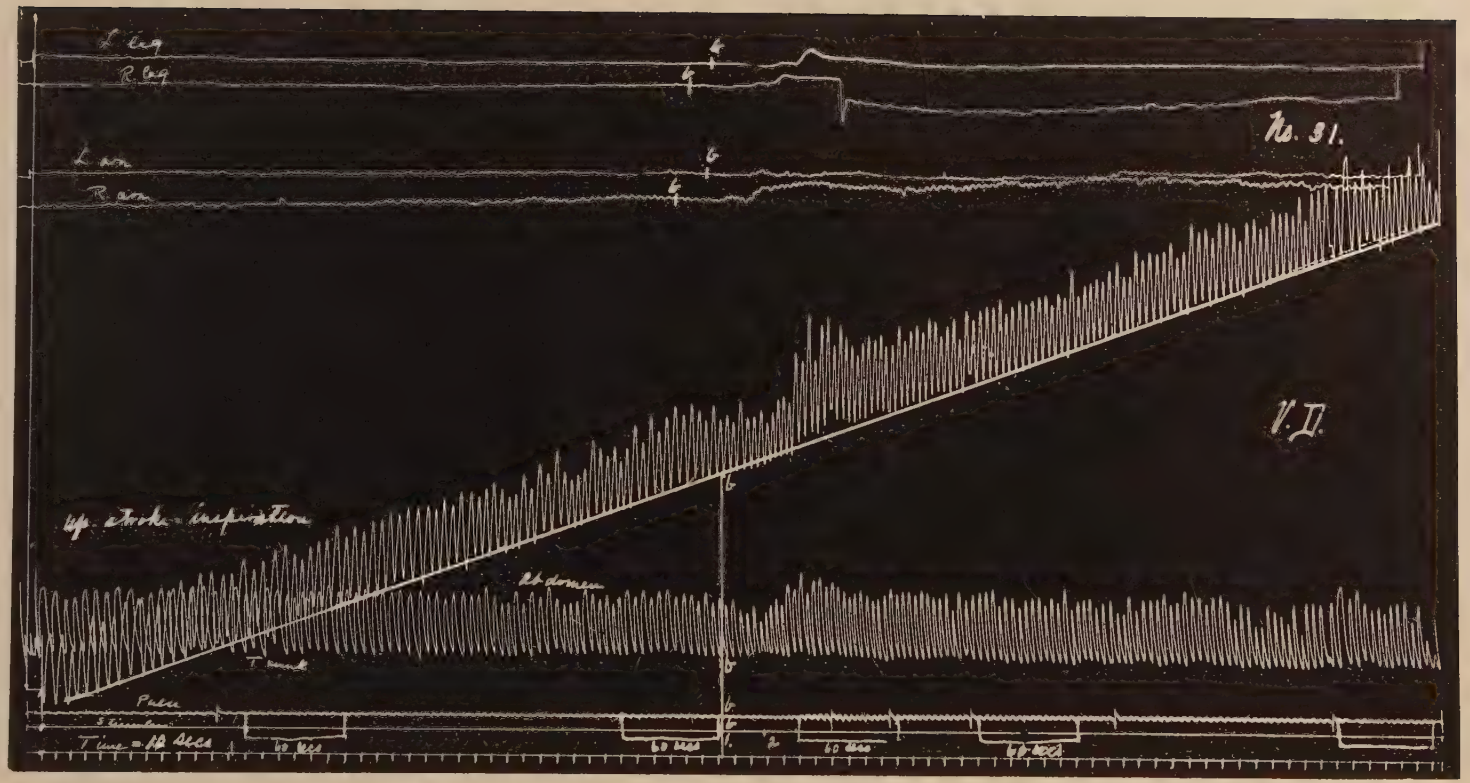
L leg
R leg
L arm
R arm
No. 31.
V. D.
Up. stroke = inspiration
Abdomen
T mark
Pulse
Time = 10 secs
60 secs

Fig. 31

worry until she knew the truth. She felt that at that moment the disturbance subsided.

The record shows a brief lift of the O_2 line during the pronounced deeper breathing after the delivery of the message, i.e., after *b*. Then it returns to its original angle and level, showing no increase in rate of oxygen consumption as a result of the clearly strong emotional excitement.

The tracings from the arms and legs show some slight movement.

The pulse shows the following changes: In the first period of 60 seconds marked off on the tracing, there are 90 beats, in the second, just before the stimulation, there are 118. In the first period of 60 seconds marked off after stimulation, that is, during the second minute of stimulation, there are 142 beats. In the third minute of stimulation the pulse has dropped to 121, and by the end of the experimental period, has fallen to 105 per minute. The quickening of the pulse just before the stimulus was given (118 beats per minute) is probably to be accounted for by the fact stated by the subject at the end of this experiment, viz., that nearly always, after she had been in the chair and had been breathing for some time from the spirometer, she would begin to think it was time for me to "do something" and to wonder what it would be. This morning the thought came to her before the knock came at the door. This was the first experiment in emotion that had been tried on her, but she had for some time been taking part in preliminary experiments in which stimuli of a different nature had been used.

Experiment 32. Subject V. D., Temperature 24°–24.5°

The stimulus in this experiment was a live snake held up before the subject. The snake had been kept in a box in the experimenting room for some time, and the subject had seen it, though she was too much afraid of it to give it more than a passing glance. As a number of persons beside myself used the room for different purposes, it was easy, with some judicious prevarication, to lead the subject to believe that the snake belonged to another student. The result was that she did not anticipate ever having

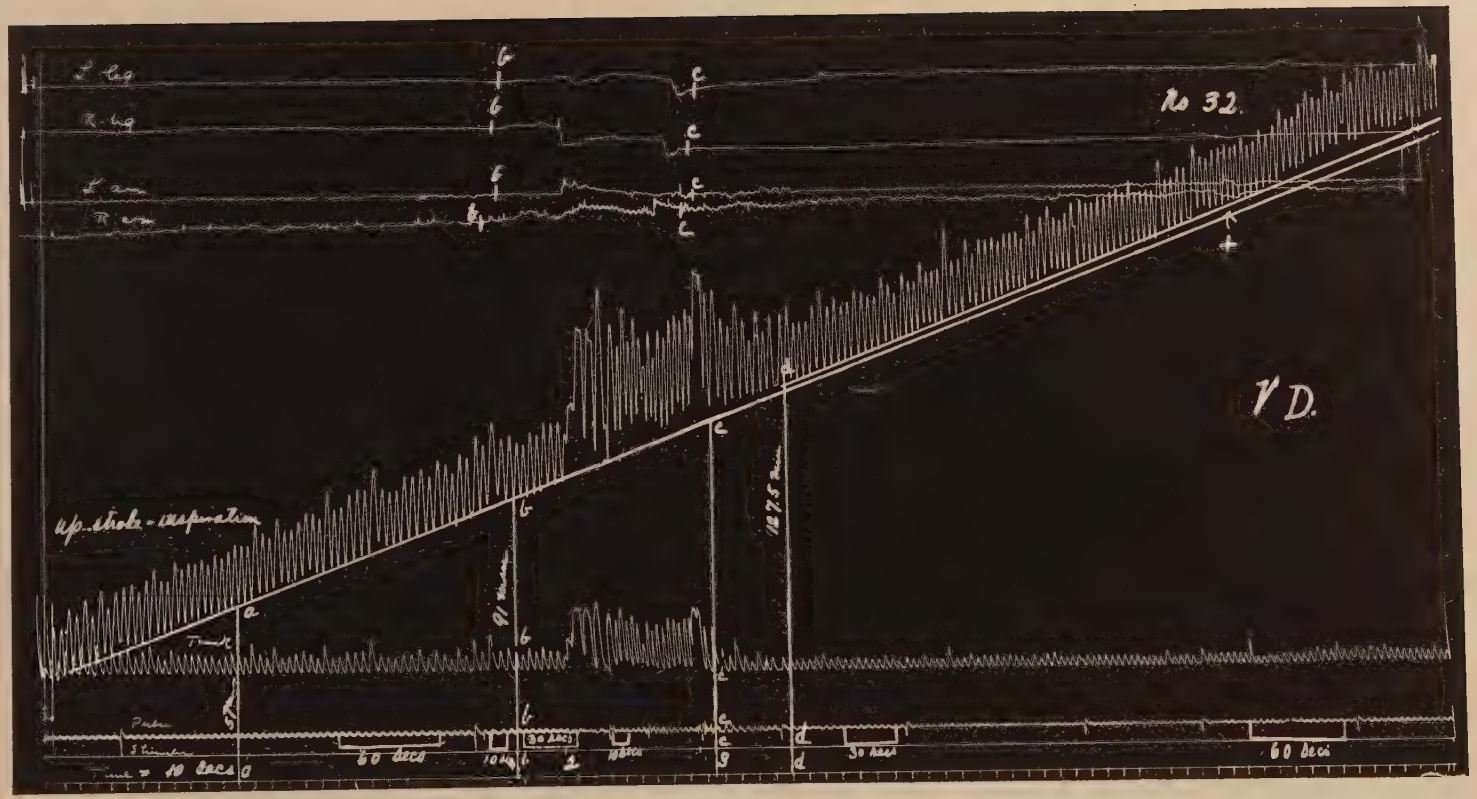

FIG. 32

it used for her, but when it was used she had no doubt of its being real.

At the first mark on the stimulus line (fig. 32), I moved to the snake's box and caught the snake by the neck. At the second mark, I said, "Mrs. D., I have the snake in my hand and in a moment I am going to remove your blind-fold and let you look at it." I immediately did so, and then I removed the snake and replaced the blind-fold at the third mark. After I spoke to the subject but before I showed her the snake, she cried out "oh" twice, as well as she could through the mouth-piece. When I held the snake up over her so that she could see it, she groaned and shook her head with every indication of horror in her expression.

Her report later was that when I spoke to her she visualized the snake, so that the experience before she saw it was much the same as afterwards, though more disagreeable when the snake was actually before her eyes. She described the experience as both dread and fear. In giving the report she made obvious efforts, more than once, to control her emotion as the tears came to her eyes.

The record shows great disturbance of respiration after the second stimulus mark and an immediate rise of the O_2 line. At *c*, when the snake was removed, the upper line begins to approach its original path, but at *d* assumes an angle a trifle greater than the original one and proceeds at a higher level. An apparent increase of 4.9 per cent in the rate of oxygen consumption is thus shown between *b* and *d*, as compared with the period *a*-*b*.

At *d* respiration returns to its normal rate and depth, so that the apparent increase in oxygen consumption is not due to continued deep breathing. Without a thoracid tracing, there remains some doubt as to whether or not the increase may be partly due to incomplete expiration and continued distension of the lungs. In any case, however, the large amount of muscular movement indicated in the arm and leg tracings, and also very evident to my observation during the experiment, would make it impossible to assume that an increase of oxygen consumption had occurred here as a result solely of internal changes. There

is, also, the further possibility that the factor of dilated bronchi has been at work.

The pulse changes, as indicated by the number of beats to be counted in the periods indicated on the tracing, are as follows: In the 60 seconds marked off in the fore-period there are 88 beats. In the 10 seconds marked just before stimulation, there are 17 beats, indicating a rate of 102 per minute (again the result, doubtless, of the subject's spontaneous expectation of a stimulus). The first 30 seconds marked off after the beginning of stimulation show 54 beats, or a rate of 108 per minute in the first minute after stimulation. In the later part of the stimulation period the pulse is too crowded to be counted with certainty, but in the ten-second period marked about 55 seconds after the beginning of the stimulation period, there are 27 beats, indicating that the pulse reached something like 162 beats per second. Seventy-five seconds after the end of stimulation, it is 110 per minute, and five and a half minutes after stimulation, it is still 102 per minute. The very rapid pulse rate of 162 beats per second comes, it is to be noted, after the second stimulus mark while the subject was looking at the snake.

IX. SUMMARY AND CONCLUSION

1. Fourteen experiments were performed in which emotional states were definitely induced.

2. In seven of these there was no indication of a change in the rate of oxygen consumption.

3. In six there were shown apparent increases of oxygen consumption following emotional stimulation. The apparent increases ranged from 4.9 to 25 per cent. The magnitude of these increases suggests the probability that they are due, at least in part, to factors other than internal change.

4. In all of these six experiments, respiration increased to a greater or less degree. Additional experiments on two subjects indicated that the increases in oxygen consumption were not due to increased activity of the respiratory muscles.

5. In all of these six experiments, also, the records show indications of tension of the muscles of arms and legs, and an attempt

was made to determine to what extent, if any, these tensions might be responsible for the apparent increases in oxygen consumption. Experiments with the dynamometer carried out with two subjects showed that considerable muscular work was possible without altering the level of the O_2 line. Since, however, it is impossible to measure the amount of muscular tension that occurred during emotion, no adequate check on this point could be had.

6. Certain features of three of these six experiments have suggested the possibility that there is a dilatation of the bronchi and bronchioles as a part of the response to emotional stimulation and independent of hyperpnea, and that a continuation of such a dilatation and consequent storing of oxygen in the air passages is the true explanation of the rise of the O_2 line and the appearance of increase in the rate of oxygen consumption.

7. One experiment suggests the possibility that with some emotions, such as pity, there is a constriction of the air passages as a part of the emotional response.

8. In experiments showing the effects of dread, disgust, sex-excitement, indignation, "excitement," the pulse shows a significant tendency to reach its maximum rate during the first minute or minute and a half of stimulation.

The results of the experiments are therefore not decisive, and even where the results appear to be positive their interpretation remains in doubt. In order to clear up, if possible, the question whether such apparent increases in oxygen consumption as have been shown are due to prolonged retention of oxygen in dilated air passages, or are in fact what they appear to be, experiments in emotion should be carried through using gas analysis and following the course of carbon dioxid output as well as that of oxygen intake. If subjects could be found in whom the ventilation of the lungs is not greatly increased in emotion, as is the case with M. B., the changes in carbon dioxid output might serve as a useful check. The technique must be so adapted as to avoid error resulting from the temporary storing of gases in the air passages which the graphic records have shown to occur during hyperpnea.

If experiments of this nature leave the matter still in doubt, the behavior of the bronchial muscles during emotion must be investigated. The behavior of the bronchial muscle in emotion is, of course, in itself of great interest and importance to psychologists independently of its bearing upon the question of oxygen consumption.

If by these procedures actual increase in oxygen consumption in emotion can be demonstrated, the part played in its production by tensions of the skeletal muscles must wait for determination upon the development of methods for measuring these tensions. If, however, it should ultimately be shown that tension of striped muscles is the cause of increased oxygen consumption under emotional stimulation, this finding would in itself be an important step toward the solution of the problem concerning the part played by skeletal muscles in emotional states.

Until these points are cleared up no final answer can be given to the question whether there is during emotion a change in the rate of oxygen consumption which may be taken as an indication of a change in the function of internal organs.

REFERENCES

(1) Barcroft, J.: The Respiratory Functions of the Blood. Cambridge, 1914.
(2) Dixon, W. E., and Ransom, F.: Broncho-dilator nerves. Jour. Physiol., 1912–1913, xlv, 413.
(3) Dunlap, K.: Elements of Scientific Psychology. St. Louis, 1922.
(4) Haldane, J. S.: Variations in the effective dead space in breathing. Amer. Jour. Physiol., 1915, xxxviii, 20.
(5) Haldane, J. S., and Douglas, C. G.: The capacity of the air passages under varying physiological conditions. Jour. Physiol., 1912, xlv, 235.
(6) Henderson, Y., Chillingworth, F. P., and Whitney, J. L.: The respiratory dead space. Amer. Jour. Physiol., 1915, xxxviii, 1.
(7) Howell, W. H.: A Text-book of Physiology. Philadelphia, 1921.
(8) Krogh, A., and Lindhard, J.: Changes in respiration at the transition from work to rest. Jour. Physiol., 1919–1920, liii, 431.
(9) Krogh, A., and Lindhard, J.: Volume of the dead space in breathing. Jour. Physiol., 1917, li, 59.
(10) Lehmann, A.: Körperliche Äusserungen Psychischer Zustände. Leipzig, 1899, vol. 1.
(11) Pearce, R. G., and Hoover, D. H.: Variations in the respiratory dead space due to changes in the depth of breathing. Amer. Jour. Physiol., 1920, lii, 472.

(12) Roth, P.: Modifications of apparatus and improved technic adaptable to the Benedict type of respiration apparatis. Boston Med. and Surg. Jour., 1922, clxxxvi, 457–465 and 491–501.
(13) Shepard, J. E.: Organic changes and feeling. Amer. Jour. Psychol., 1906, xvii, 522.

VITA

Edith Totten was born October 7, 1879, in Washington, D. C. She entered the Friends' School in Washington in the autumn of 1887 and graduated from there in June, 1897. After a year at the Baldwin School at Bryn Mawr, Pa., she entered Bryn Mawr College in 1898 and received the degree of A.B. in 1902. In 1917 she entered the Graduate School of Columbia University, doing part time work for two years and receiving the degree of A.M. in 1919. The work for the degree of Doctor of Philosophy was begun at the Johns Hopkins University in 1920 and was carried on continuously until 1924, the major subject being Psychology and the subordinate subjects, Physiology and Psychiatry.